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Background Information for Proposed Standards

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Standards of performance to control emissions of volatile organic compounds (VOC) from new, modified, and reconstructed synthetic fiber production facilities are being proposed under section 111 of the Clean Air Act. This document contains information on the background and authority, regulatory alternatives considered, and environmental and economic impacts of the regulatory alternatives.

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Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

October 1982

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ENVIRONMENTAL PROTECTION AGENCY

Background Information
and Draft
Environmental Impact Statement
for Synthetic Fiber Production Facilities

Prepared by:

October 8, 1982
(Date)

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1. The proposed standards of performance would limit emissions of volatile organic compounds from new, modified, and reconstructed synthetic fiber production facilities. Section 111 of the Clean Air Act (42 U.S.C. 7411), as amended, directs the Administrator to establish standards of performance for any category of new stationary source of air pollution that ". . . causes or contributes significantly to air pollution which may reasonably be anticipated to endanger public health or welfare." EPA Regions I, II, III, and IV are particularly affected, since most synthetic fiber production facilities are located in these regions.

2. Copies of this document have been sent to the following Federal Departments: Labor, Health and Human Services, Defense, Transportation, Agriculture, Commerce, Interior, and Energy; the National Science Foundation; the Council on Environmental Quality; members of the State and Territorial Air Pollution Program Administrators; the Association of Local Air Pollution Control Officials; EPA Regional Administrators; and other interested parties.

3. The comment period for review of this document is 60 days. Mr. Gene Smith may be contacted regarding the date of the comment period.

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1.0 SUMMARY

1.1 REGULATORY ALTERNATIVES

Standards of performance for new, modified, or reconstructed affected facilities at solvent spun synthetic and semisynthetic fiber manufacturing plants are being proposed under Section 111 of the Clean Air Act. The proposed standard would limit volatile organic compound (VOC) emissions, the major air pollutant emitted from synthetic fiber plants.

The regulatory alternatives evaluated in this document would reduce VOC emissions from affected facilities at synthetic and semisynthetic fiber production plants which use an organic solvent in dissolving the polymer or in the precipitation bath. This would include such fiber types as acrylic, modacrylic, cellulose acetate, and spandex.

Three regulatory alternatives were considered: Alternative I would require no additional control beyond baseline; Alternative II would require a 31 to 55 percent reduction in VOC emissions by capturing VOC emissions from the areas of highest concentration and/or the areas most easily controlled; and Alternative III would require a 60 to 76 percent reduction by extending the capture techniques to additional processing points and by capturing a larger portion of all fugitive and stack emissions. The demonstrated use of high efficiency solvent recovery systems at existing plants and the increasing value of the recovered solvent suggest that improvement in recovery system efficiency is the only reasonable alternative for VOC control.

1.2 ENVIRONMENTAL/ECONOMIC IMPACT

Under Regulatory Alternative II, which suggests control of VOC emissions from those areas of greatest VOC concentrations, projected 1987 VOC emissions from new synthetic and semisynthetic fiber capacity would be reduced by as much as 5.6 gigagrams (Gg). This is equivalent to a reduction of VOC emissions of as much as 44 percent when compared to baseline (Regulatory Alternative I) emissions projected for the same year.

If Regulatory Alternative III were implemented, 1987 VOC emissions would be reduced by up to 63 percent over projected baseline emissions. VOC emissions in 1987 from new synthetic and semisynthetic capacity would be reduced by as much as 8.5 Gg.

The fifth-year water pollution and solid waste impacts of Regulatory Alternatives II and III each represent minimal increases over baseline figures. The control options are based on the use of carbon adsorbers or absorption scrubbers to reduce VOC emissions. Insignificant amounts of water pollution and solid waste would be generated by the control equipment required, and nearly all captured VOC's would be reclaimed. Therefore, both Alternatives II and III would have little or no adverse impact on water quality or solid waste.

There would be only a minimal apparent increase in energy consumption at a given plant as a result of either Alternative II or III. A typical plant in the industry would increase energy use by about 2 and 3 percent as a result of implementing Alternatives II and III, respectively.

Capital and operating costs for manufacture of each of the fiber types considered were developed and analyzed. Total (fixed plus working) capital costs of emission control equipment required at model plants analyzed range from $1.3 to $8.2 million for Regulatory Alternative II, and $3.0 to $10.4 million for Regulatory Alternative III. Increases in annual operating costs for additional emission control equipment at these model plants range from $0.3 million to $1.4 million for Alternative II, and $0.6 to $1.7 million for Alternative III (see page 8-5).

The economic effects on the industry were projected to the fifth year following proposal, and reflect the most likely circumstances. The total annualized costs to the entire industry would be as much as $7.4 million, but this would be offset to a large extent by additional solvent recovery resulting from improved emission control. The net annualized cost in 1987 would amount to $1.2 million for either Regulatory Alternative (see pages 8-21 and 9-93).

The complete economic impact analysis appears in Chapter 9. A summary of the economic impacts of the proposed emission limits is also presented in Table 1-1.

Table 1-1. MATRIX OF ENVIRONMENTAL, ENERGY, AND ECONOMIC IMPACTS OF REGULATORY ALTERNATIVES

Administrative Action	Air Impact	Water Impact	Solid Waste Impact	Energy Impact	Economic Impact
Alternative I	0	0	0	0	0*
Alternative II	+3**	0	-1**	-1**	-1**
Alternative III	+3**	0	-1**	-1**	-1**

KEY

+	Beneficial Impact
-	Adverse Impact
0	No Impact
1	Negligible Impact
2	Small Impact
3	Moderate Impact
4	Large Impact
*	Short-Term Impact
**	Long-Term Impact
***	Irreversible Impact

2. INTRODUCTION

2.1 BACKGROUND AND AUTHORITY FOR STANDARDS

Before standards of performance are proposed as a Federal regulation, air pollution control methods available to the affected industry and the associated costs of installing and maintaining the control equipment are examined in detail. Various levels of control based on different technologies and degrees of efficiency are expressed as regulatory alternatives. Each of these alternatives is studied by EPA as a prospective basis for a standard. The alternatives are investigated in terms of their impacts on the economics and well-being of the industry, the impacts on the national economy, and the impacts on the environment. This document summarizes the information obtained through these studies so that interested persons will be able to see the information considered by EPA in the development of the proposed standard.

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 U.S.C. 7411) as amended, hereinafter referred to as the Act. Section 111 directs the Administrator to establish standards of performance for any category of new stationary source of air pollution which "... causes, or contributes significantly to air pollution which may reasonably be anticipated to endanger public health or welfare."

The Act requires that standards of performance for stationary sources reflect,"... the degree of emission reduction achievable which (taking into consideration the cost of achieving such emission reduction, and any nonair quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated for that category of sources." The standards apply only to stationary sources, the construction or modification of which commences after regulations are proposed by publication in the Federal Register.

The 1977 amendments to the Act altered or added numerous provisions that apply to the process of establishing standards of performance.

1. EPA is required to list the categories of major stationary sources that have not already been listed and regulated under standards of performance. Regulations must be promulgated for these new categories on the following schedule:

   a. 25 percent of the listed categories by August 7, 1980.
   b. 75 percent of the listed categories by August 7, 1981.
   c. 100 percent of the listed categories by August 7, 1982.

A governor of a State may apply to the Administrator to add a category not on the list or may apply to the Administrator to have a standard of performance revised.

2. EPA is required to review the standards of performance every four years and, if appropriate, revise them.

3. EPA is authorized to promulgate a standard based on design, equipment, work practice, or operational procedures when a standard based on emission levels is not feasible.

4. The term "standards of performance" is redefined, and a new term "technological system of continuous emission reduction" is defined. The new definitions clarify that the control system must be continuous and may include a low- or non-polluting process or operation.

5. The time between the proposal and promulgation of a standard under Section 111 of the Act may be extended to six months.

Standards of performance, by themselves, do not guarantee protection of health or welfare because they are not designed to achieve any specific air quality levels. Rather, they are designed to reflect the degree of emission limitation achievable through application of the best adequately demonstrated technological system of continuous emission reduction, taking into consideration the cost of achieving such emission reduction, any nonair quality health and environmental impacts, and energy requirements.

Congress had several reasons for including these requirements. First, standards with a degree of uniformity are needed to avoid situations where some States may attract industries by relaxing standards relative to other States. Second, stringent standards enhance the potential for long-term growth. Third, stringent standards may help achieve long-term cost savings by avoiding the need for more retrofitting when pollution ceilings may be reduced in the future. Fourth, certain types of standards for coal-burning sources can adversely affect the coal market by driving up the price of low-sulfur coal or effectively excluding certain coals from the reserve base because their untreated pollution potentials are high. Congress does not intend that new source performance standards contribute to these problems. Fifth, the standard-setting process should create incentives for improved technology.

Promulgation of standards of performance does not prevent State or local agencies from adopting more stringent emission limitations for the same sources. States are free under Section 116 of the Act to establish even more stringent emission limits than those established under Section 111 or those necessary to attain or maintain the National Ambient Air Quality Standards (NAAQS) under Section 110. Thus, new sources may in some cases be subject to limitations more stringent than standards of performance under Section 111, and prospective owners and operators of new sources should be aware of this possibility in planning for such facilities.

A similar situation may arise when a major emitting facility is to be constructed in a geographic area that falls under the prevention of significant deterioration of air quality provisions of Part C of the Act. These provisions require, among other things, that major emitting facilities to be constructed in such areas are to be subject to best available control technology. The term Best Available Control Technology (BACT), as defined in the Act, means

> ... an emission limitation based on the maximum degree of reduction of each pollutant subject to regulation under this Act emitted from, or which results from, any major emitting facility, which the permitting authority, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such facility through application of production processes and available methods, systems, and techniques, including fuel cleaning or treatment or innovative fuel combustion techniques for control of each such pollutant. In no event shall application of "best available control technology" result in emissions of any pollutants which will exceed the emissions allowed by any applicable standard established pursuant to Sections 111 or 112 of this Act. (Section 169(3))

Although standards of performance are normally structured in terms of numerical emission limits where feasible, alternative approaches are sometimes necessary. In some cases physical measurement of emissions from a new source may be impractical or exorbitantly expensive. Section 111(h) provides that the Administrator may promulgate a design or equipment standard in those cases where it is not feasible to prescribe or enforce a standard of performance. For example, emissions of hydrocarbons from storage vessels for petroleum liquids are greatest during tank filling. The nature of the emissions, high concentrations for short periods during filling and low concentrations for longer periods during storage, and the configuration of storage tanks make direct emission measurement impractical. Therefore, a more practical approach to standards of performance for storage vessels has been equipment specification.

In addition, Section 111(j) authorizes the Administrator to grant waivers of compliance to permit a source to use innovative continuous emission control technology. In order to grant the waiver, the Administrator must find: (1) a substantial likelihood that the technology will produce greater emission reductions than the standards require or an equivalent reduction at lower economic energy or environmental cost; (2) the proposed system has not been adequately demonstrated; (3) the technology will not cause or contribute to an unreasonable risk to the public health, welfare, or safety; (4) the governor of the State where the source is located consents; and (5) the waiver will not prevent the attainment or maintenance of any ambient standard. A waiver may have conditions attached to assure the source will not prevent attainment of any NAAQS. Any such condition will have the force of a performance standard. Finally, waivers have definite end dates and may be terminated earlier if the conditions are not met or if the system fails to perform as expected. In such a case, the source may be given up to three years to meet the standards with a mandatory progress schedule.

2.2 SELECTION OF CATEGORIES OF STATIONARY SOURCES

Section 111 of the Act directs the Adminstrator to list categories of stationary sources. The Administrator "... shall include a category of sources in such list if in his judgment it causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." Proposal and promulgation of standards of performance are to follow.

Since passage of the Clean Air Act of 1970, considerable attention has been given to the development of a system for assigning priorities to various source categories. The approach specifies areas of interest by considering the broad strategy of the Agency for implementing the Clean Air Act. Often, these "areas" are actually pollutants emitted by stationary sources. Source categories that emit these pollutants are evaluated and ranked by a process involving such factors as: (1) the level of emission control (if any) already required by State regulations, (2) estimated levels of control that might be required from standards of performance for the source category, (3) projections of growth and replacement of existing facilities for the source category, and (4) the estimated incremental amount of air pollution that could be prevented in a preselected future year by standards of performance for the source category. Sources for which new source performance standards were promulgated or under development during 1977, or earlier, were selected on these criteria.

The Act amendments of August 1977 establish specific criteria to be used in determining priorities for all major source categories not yet listed by EPA. These are: (1) the quantity of air pollutant emissions that each such category will emit, or will be designed to emit; (2) the extent to which each such pollutant may reasonably be anticipated to endanger public health or welfare; and (3) the mobility and competitive nature of each such category of sources and the consequent need for nationally applicable new source standards of performance.

The Administrator is to promulgate standards for these categories according to the schedule referred to earlier.

In some cases it may not be feasible immediately to develop a standard for a source category with a high priority. This might happen when a program of research is needed to develop control techniques or because techniques for sampling and measuring emissions may require refinement. In the developing of standards, differences in the time required to complete the necessary investigation for different source categories must also be considered. For example, substantially more time may be necessary if numerous pollutants must be investigated from a single source category. Further, even late in the development process the schedule for completion of a standard may change. For example, inability to obtain emission data from well-controlled sources in time to pursue the development process in a systematic fashion may force a change in scheduling. Nevertheless, priority ranking is, and will continue to be, used to establish the order in which projects are initiated and resources assigned.

After the source category has been chosen, the types of facilities within the source category to which the standard will apply must be determined. A source category may have several facilities that cause air pollution, and emissions from some of these facilities may vary from insignificant to very expensive to control. Economic studies of the source category and of applicable control technology may show that air pollution control is better served by applying standards to the more severe pollution sources. For this reason, and because there is no adequately demonstrated system for controlling emissions from certain facilities, standards often do not apply to all facilities at a source. For the same reasons, the standards may not apply to all air pollutants emitted. Thus, although a source category may be selected to be covered by a standard of performance, not all pollutants or facilities within that source category may be covered by the standards.

2.3 PROCEDURE FOR DEVELOPMENT OF STANDARDS OF PERFORMANCE

Standards of performance must (1) realistically reflect best demonstrated control practice; (2) adequately consider the cost, the nonair quality health and environmental impacts, and the energy requirements of such control; (3) be applicable to existing sources that are modified or reconstructed as well as new installations; and (4) meet these conditions for all variations of operating conditions being considered anywhere in the country.

The objective of a program for developing standards is to identify the best technological system of continuous emission reduction that has been adequately demonstrated. The standard-setting process involves three principal phases of activity: (1) information gathering, (2) analysis of the information, and (3) development of the standard of performance.

During the information-gathering phase, industries are queried through a telephone survey, letters of inquiry, and plant visits by EPA representatives. Information is also gathered from many other sources, and a literature search is conducted. From the knowledge acquired about the industry, EPA selects certain plants at which emission tests are conducted to provide reliable data that characterize the pollutant emissions from well-controlled existing facilities.

In the second phase of a project, the information about the industry and the pollutants emitted is used in analytical studies. Hypothetical "model plants" are defined to provide a common basis for analysis. The model plant definitions, national pollutant emission data, and existing State regulations governing emissions from the source category are then used in establishing "regulatory alternatives." These regulatory alternatives are essentially different levels of emission control.

EPA conducts studies to determine the impact of each regulatory alternative on the economics of the industry and on the national economy, on the environment, and on energy consumption. From several possibly applicable alternatives, EPA selects the single most plausible regulatory alternative as the basis for a standard of performance for the source category under study.

In the third phase of a project, the selected regulatory alternative is translated into a standard of performance, which, in turn, is written in the form of a Federal regulation. The Federal regulation, when applied to newly constructed plants, will limit emissions to the levels indicated in the selected regulatory alternative.

As early as is practical in each standard-setting project, EPA representatives discuss the possibilities of a standard and the form it might take with members of the National Air Pollution Control Techniques Advisory Committee. Industry representatives and other interested parties also participate in these meetings.

The information acquired in the project is summarized in the Background Information Document (BID). The BID, the standard, and a preamble explaining the standard are widely circulated to the industry being considered for control, environmental groups, other government agencies, and offices within EPA. Through this extensive review process, the points of view of expert reviewers are taken into consideration as changes are made to the documentation.

A "proposal package" is assembled and sent through the offices of EPA Assistant Administrators for concurrence before the proposed standard is officially endorsed by the EPA Administrator. After being approved by the EPA Administrator, the preamble and the proposed regulation are published in the Federal Register.

As a part of the Federal Register announcement of the proposed regulation, the public is invited to participate in the standard-setting process. EPA invites written comments on the proposal and also holds a public hearing to discuss the proposed standard with interested parties. All public comments are summarized and incorporated into a second volume of the BID. All information reviewed and generated in studies in support of the standard of performance is available to the public in a "docket" on file in Washington, D. C.

Comments from the public are evaluated, and the standard of performance may be altered in response to the comments.

The significant comments and EPA's position on the issues raised are included in the "preamble" of a "promulgation package," which also contains the draft of the final regulation. The regulation is then subjected to another round of review and refinement until it is approved by the EPA Administrator. After the Administrator signs the regulation, it is published as a "final rule" in the Federal Register.

2.4 CONSIDERATION OF COSTS

Section 317 of the Act requires an economic impact assessment with respect to any standard of performance established under Section 111 of the Act. The assessment is required to contain an analysis of: (1) the costs of compliance with the regulation, including the extent to which the cost of compliance varies depending on the effective date of the regulation and the development of less expensive or more efficient methods of compliance; (2) the potential inflationary or recessionary effects of the regulation; (3) the effects the regulation might have on small business with respect to competition; (4) the effects of the regulation on consumer costs; and (5) the effects of the regulation on energy use. Section 317 also requires that the economic impact assessment be as extensive as practicable.

The economic impact of a proposed standard upon an industry is usually addressed both in absolute terms and in terms of the control costs that would be incurred as a result of compliance with typical, existing State control regulations. An incremental approach is necessary because both new and existing plants would be required to comply with State regulations in the absence of a Federal standard of performance. This approach requires a detailed analysis of the economic impact from the cost differential that would exist between a proposed standard of performance and the typical State standard.

Air pollutant emissions may cause water pollution problems, and captured potential air pollutants may pose a solid waste disposal problem. The total environmental impact of an emission source must, therefore, be analyzed and the costs determined whenever possible.

A thorough study of the profitability and price-setting mechanisms of the industry is essential to the analysis so that an accurate estimate of potential adverse economic impacts can be made for proposed standards. It is also essential to know the capital requirements for pollution control systems already placed on plants so that the additional capital requirements necessitated by these Federal standards can be placed in proper perspective. Finally, it is necessary to assess the availability of capital to provide the additional control equipment needed to meet the standards of performance.

2.5 CONSIDERATION OF ENVIRONMENTAL IMPACTS

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the decisionmaking process of Federal agencies a careful consideration of all environmental aspects of proposed actions.

In a number of legal challenges to standards of performance for various industries, the United States Court of Appeals for the District of Columbia Circuit has held that environmental impact statements need not be prepared by the Agency for proposed actions under Section 111 of the Clean Air Act. Essentially, the Court of Appeals has determined that the best system of emission reduction requires the Administrator to take into account counter-productive environmental effects of a proposed standard, as well as economic costs to the industry. On this basis, therefore, the Court established a narrow exemption from NEPA for EPA determination under Section 111.

In addition to these judicial determinations, the Energy Supply and Environmental Coordination Act (ESECA) of 1974 (PL-93-319) specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to Section 7(c)(1), "No action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969." (15 U.S.C. 793(c)(1))

Nevertheless, the Agency has concluded that the preparation of environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, although not legally required to do so by Section 102(2)(C) of NEPA, EPA has adopted a policy requiring that environmental impact statements be prepared for various regulatory actions, including standards of performance developed under Section 111 of the Act. This voluntary preparation of environmental impact statements, however, in no way legally subjects the Agency to NEPA requirements.

To implement this policy, a separate section in this document is devoted solely to an analysis of the potential environmental impacts associated with the proposed standards. Both adverse and beneficial impacts in such areas as air and water pollution, increased solid waste disposal, and increased energy consumption are discussed.

2.6 IMPACT ON EXISTING SOURCES

Section 111 of the Act defines a new source as "... any stationary source, the construction or modification of which is commenced ..." after the proposed standards are published. An existing source is redefined as a new source if "modified" or "reconstructed" as defined in amendments to the general provisions of Subpart A of 40 CFR Part 60, which were promulgated in the Federal Register on December 16, 1975 (40 FR 58416).

Promulgation of a standard of performance requires States to establish standards of performance for existing sources in the same industry under Section 111(d) of the Act if the standard for new sources limits emissions of a designated pollutant (i.e., a pollutant for which air quality criteria have not been issued under Section 108 or which has not been listed as a hazardous pollutant under Section 112). If a State does not act, EPA must establish such standards. General provisions outlining procedures for control of existing sources under Section 111(d) were promulgated on November 17, 1975, as Subpart B of 40 CFR Part 60 (40 FR 53340).

2.7 REVISION OF STANDARDS OF PERFORMANCE

Congress was aware that the level of air pollution control achievable by any industry may improve with technological advances. Accordingly, Section 111 of the Act provides that the Administrator "... shall, at least every 4 years, review and, if appropriate, revise ..." the standards. Revisions are made to assure that the standards continue to reflect the best systems that become available in the future. Such revisions will not be retroactive, but will apply to stationary sources constructed or modified after the proposal of the revised standards.

3.0 INDUSTRY DESCRIPTION

3.1 GENERAL INFORMATION

Man-made fibers include two types of products, the semisynthetics or cellulosics (e.g., viscose rayon and cellulose acetate) and the true synthetics or noncellulosics (e.g., polyester, nylon, acrylic and modacrylic, spandex, and polyolefin). These seven fiber types comprise over 99 percent of the total production of man-made fibers in the U.S. Table 3-1 lists these fibers and gives the approximate relative production percentage of the total man-made fibers market they held in 1980. Table 3-2 lists the man-made fiber production facilities, plant locations, and fiber types as of 1980.

Semisynthetics are formed when naturally occurring polymeric materials such as cellulose are dissolved or dispersed into a suitable solvent, and then spun into fine filaments. True synthetics result from the formation (polymerization) of long chain molecules from (usually) petroleum derivatives. The polymer is then dissolved or melted and spun into fiber form. Figure 3-1 gives a generalized schematic process diagram for the production of synthetic fibers.

3.1.1 Man-Made Fiber Processing[1-7]

The major fiber spinning processes are melt, dry, and wet spinning. Reaction spinning is also used but to a far lesser extent. The spinning process used for a particular polymer depends on its melting point, melt stability, and solubility in organic solvents. A detailed description of each of these spinning processes is given below, along with a description of the most significant post-spinning fiber treatment processes. Process descriptions and diagrams for each individual fiber type are provided in Chapter 6.

3.1.1.1 Viscose Rayon. Rayon fibers are defined by the Federal Trade Commission as "a manufactured fiber composed of regenerated cellulose, as well as manufactured fibers composed of regenerated cellulose in

Table 3-1. RELATIVE PRODUCTION PERCENTAGES OF MAN-MADE FIBERS[1-4] (1980)

Semisynthetics:	Cellulose Acetate and Triacetate	7.0 percent
	Rayon	5.7
Synthetics:	Polyester	44.9
	Nylon	26.1
	Acrylic and Modacrylic	8.4
	Polyolefin	7.4
	Spandex	0.1
	Total	99.6 percent

Table 3-2. SYNTHETIC FIBER MANUFACTURING COMPANIES[2,5] (1980)

Company	Location	Fibers Produced
ACS Industries	Woonsocket, RI	PYO
	Walthourville, GA	PYO
Allied Chemical	Hopewell, VA	N
	Columbia, SC	P,N
	Moncure, NC	P
	Chesterfield, VA	N
	Irmo, SC	N
	West Conshohocken, PA	N
Alrac Corp.	Stamdford, Conn.	N
Ameliotex, Inc.	Rocky Hill, NJ	S
American Cyanamid	Milton, FL	A
	Painesville, OH	P
American Enka	Lowland, TN	R,N
	Enka, NC	N
	Central, SC	P,N
American Kynol, Inc.	Sanborn, NY	NO
American Hoechst	Spartanburg, SC	P
	Delaware City, Del.	P
American Mfg. Co.	Honesdale, PA	PYO
	Layfayette, LA	PYO
	St. Louis, MO	PYO
Amoco Fabrics Co. (Subsid. Standard Oil Co.)	Bainbridge, GA	PYO
	Hazelhurst, GA	PYO
	Nashville, GA	PYO
Amtech, Inc.	Odenton, MD	PYO, N, P
Andray Products	East Orange, NJ	PYO
Arlin Mfg. Co.	Lowell, MA	PYO
Armstrong Cork Co.	Charlotte, NC	PYO
Avtex	Front Royal, VA	R,P
	Meadville, PA	V,P
		R,P
Badische	Williamsburg, VA	A
	Anderson, SC	P,N

Table 3-2. SYNTHETIC FIBER MANUFACTURING COMPANIES (Continued)

Company	Location	Fibers Produced
Barnet Southern Corp.	Spartanburg, SC	NonCellulosics
Beaunit Corp.	Elizabethton, TN	P, N, PYO
Bemis Co. Inc.	St. Louis, MO Talladega, AL	PYO
Berkley & Co.	Spirit Lake, IA	PYO, N
Camac Corp.	Bristol, VA	N, PYO
Carborundum Company	Niagra Falls, NY	NO
Carolina Eastman (Eastman Kodak)	Columbia, SC	P
Carter Moore Process. Corp.	Summerville, SC	Noncellulosics
Celanese Fibers Co.	Rock Hill, SC	AC
	Cumberland, MD	AC
	Narrows, VA	AC
	Summit, NJ	PBI
Chadbourn, Inc. Chadbourn Indust. Div. Chadol Division	Gainesville, GA	N
Chase Bag Co.	Orange, CA	PYO
	New Orleans, LA	PYO
Chevron (Standard Oil)	Guayama, PR	N
Chevron Chem. Co. (Standard Oil)	Dayton, TN	PYO
Columbia Rope Co. Cordage Group Div.	Auburn, NY	PYO
Concorde Fibers Inc.	Columbia, MD	PYO
Courtaulds, N.A.	LeMoyne, AL	N
Crowe Rope Co. Div of A. Crowe & Sons, Inc.	Warren, ME	PYO

Table 3-2. SYNTHETIC FIBER MANUFACTURING COMPANIES (Continued)

Company	Location	Fibers Produced
Diversified Indust. Inc. Synthetic Indust. Inc., Subsid. Tennessee Fibers, Subsid.	Chickamauga, GA	PYO
	Pecatur, TN	PYO
DuPont Corp.	Charleston, SC	P,N
	Camden, SC	A,N,P
	Waynesboro, VA	A,N,P
	Cape Fear, NC	P
	Old Hickory, TN	P
	Richmond, VA	AR,N,P
	Martinsville, VA	N,P
	Chattanooga, TN	N,P
	Seaford, DE	N,P
	Wilmington, NC	P,N
	Kinston, NC	P,N
	Parkersburg, W VA	N
E.B. Indus. Inc.	Simsbury, CN	PYO,N,P
Exxon Corp.	Summerville, SC	PYO
	Kingman, TX	PYO
	Tracy, MN	
Falk Fibers & Fabric	Fuquay-Varina, NC	P
	Yanceyville, NC	N
Fiber Indus. Inc. (Celanese Co.)	Greenville, SC	P
	Shelby, NC	P
	Florence, SC	P
	Salisbury, NC	P
FIBRON, Inc.	Chatanooga, TN	PYO
Fibrex (Solvex Corp.)	Humacao, PR	P
Firestone	Hopewell, VA	N,P
FNT Indus. Inc.	Menominee, MI	PYO
General Fiber & Fabrics Corp.	LaGrange, GA	PYO
Georgia Synthetics, Inc.	Elberton, GA	PYO

Table 3-2. SYNTHETIC FIBER MANUFACTURING COMPANIES (Continued)

Company	Location	Fibers Produced
Globe Mfg. Co.	Gastonia, NC	S
	Fall River, MA	S
Goodyear	Scottsboro, AL	P
	Point Pleasant, W VA	P
Guilford Mills	Gainesville, GA	N
Hanover Mills	Yanceyville, NC	N
Hercules, Inc.	Covington, VA	PYO
	Oxford, GA	PYO
Hoover & Allison Co.	Xenia, OH	PYO
International Harvester Co.	New Orleans, LA	PYO
Indian Head, Inc.	Blue Mountain, AL	PYO
Kayser-Roth Corp.	Creedmoor, NC	N
Keller Indus. Inc.	Swainsboro, GA	PYO
Lambeth Corp.	New Bedford, MA	PYO
Lawrence Hose Co. (subs. Consolidated Foods Corp.)	Burlington, NC	PYO
Meyers Fibers, Inc.	Ansonville, SC	P
Monofilaments, Inc.	Waynesboro, VA	N,P,PYO
Monsanto Fibers Co.	Decatur, AL	A,P,N
	Sand Mountain, AL	P,N
	Pensacola, FL	N
	Greenwood, SC	N
	Fayetteville, NC	P,N
Moultrie Cotton Mills, Inc.	Moultrie, GA	PYO
Newton Filaments, Inc.	Homer, NY	PYO
North American Rayon	Elizabethton, TN	R
NSI, Inc.	Soperton, Ga	PYO

Table 3-2. SYNTHETIC FIBER MANUFACTURING COMPANIES (Continued)

Company	Location	Fibers Produced
Olvind Lorentzen	Guilderland Center, NY	PYO
Osterneck Co.	Lumberton, NC	PYO
Poncar Plastic Corp.	Miami, FL	PYO
Phillips Fibers, Inc.	Rocky Mount, NC	P
	Spartanburg, SC	PYO
	Guayama, PR	N,P
Plant Indus., Inc.	Houston, TX	PYO
Plataril Co.	Birdsboro, PA	N
Rohm and Haas	Fayetteville, NC	N,P
Shakespeare Co.	Columbia, SC	N,P
Star Fibers, Inc.	Edgefield, SC	N
Shuford Mills, Inc.	Hickory, NC	PYO
Sunburst Yarns, Inc.	Afton, VA	N
Sunshine Cordage	Miami, FL	PYO
Synthon Textile, Inc.	Asheville, NC	P
Tennessee Eastman (Eastman Kodak)	Columbia, SC	P
	Kingsport, TN	A,P AC,P N,P PYO,P
Texfi Indus., Inc.	Asheboro, NC	P
	New Bern, NC	P
	Kinston, NC	P
	Liberty, NC	P
Thiokol Corp.	Waynesboro, VA	PYO
Tubbs Cordage	Reading, PA	PYO
	Orange, PA	PYO
Uniroyal, Inc. Uniroyal Fiber & Textile Div.	Winnsboro, SC	N,PYO

Table 3-2. SYNTHETIC FIBER MANUFACTURING COMPANIES (Concluded)

Company	Location	Fibers Produced
Vectra Corp. (sub. Standard Oil)	Odenton, MD	PYO
Volplex Corp.	Canandaigua, NY	V,PYO
Well Indus. Inc.	Beverly, NJ	PYO
Waltrich Plastic	Tennent, NJ	PYO
Wellington Tech. Ind.	Pilot Mountain, NC	PYO
	Leesville, SC	PYO
	Summerville, SC	PYO
	Trussville, AL	PYO
Wellman, Inc.	Johnsonville, SC	N,P
Whitaker, Fred, Co.	Raleigh, NC	P
Yadtex, Inc.	Mount Airy, NC	P

A = Acrylics
AC = Acetate
N = Nylon
NO = Noveloid
V = Vinyon
R = Rayon
S = Spandex
P = Polyester
PBI = Polybenzimidazole
PC = Polycarbonate
AR = Aramid
PYO = Polyolefin

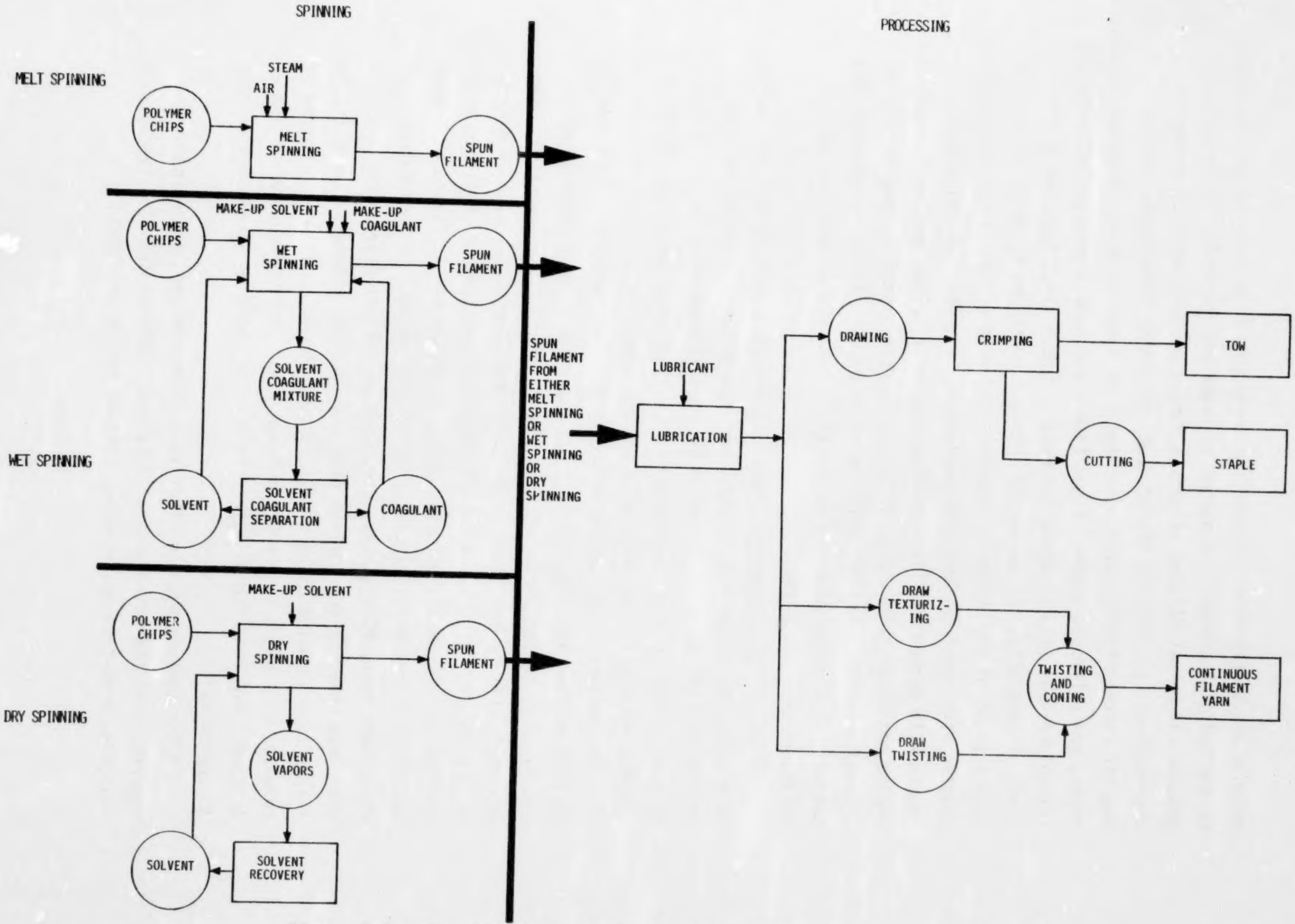

SPINNING
PROCESSING
MELT SPINNING
STEAM
AIR
POLYMER CHIPS
MELT SPINNING
SPUN FILAMENT
MAKE-UP SOLVENT
MAKE-UP COAGULANT
POLYMER CHIPS
WET SPINNING
SPUN FILAMENT
SOLVENT COAGULANT MIXTURE
WET SPINNING
SOLVENT
SOLVENT COAGULANT SEPARATION
COAGULANT
MAKE-UP SOLVENT
POLYMER CHIPS
DRY SPINNING
SPUN FILAMENT
DRY SPINNING
SOLVENT VAPORS
SOLVENT
SOLVENT RECOVERY
SPUN FILAMENT FROM EITHER MELT SPINNING OR WET SPINNING OR DRY SPINNING
LUBRICANT
LUBRICATION
DRAWING
CRIMPING
TOW
CUTTING
STAPLE
DRAW TEXTURIZ-ING
TWISTING AND CONING
CONTINUOUS FILAMENT YARN
DRAW TWISTING

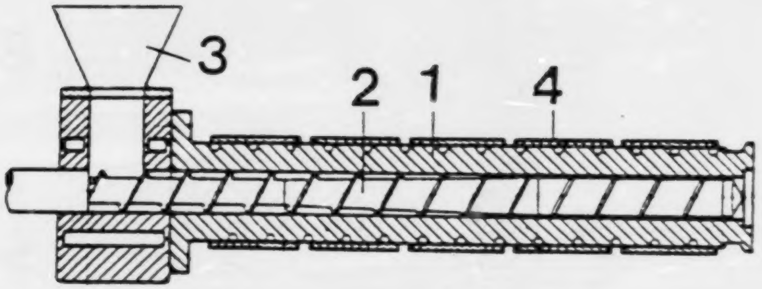
Figure 3-1. Process Flow Diagram for Melt, Wet or Dry Spun Synthetic Fibers

which substituents have replaced not more than 15 percent of the hydrogens of the hydroxyl groups." A number of important variables in the viscose process can be manipulated to obtain fibers of substantially different characteristics. Broadly categorized, the rayon fiber types include regular (conventional) rayon, modified high tenacity rayon, high-wet-modulus rayon, and polymosic rayon. Rayon fibers are made from chemical cellulose (dissolved wood pulp), sodium hydroxide, carbon disulfide, and sulfuric acid. Essentially, the series of chemical reactions by which viscose is made consist of the following stages: (1) Wood cellulose and concentrated caustic soda react to form soda cellulose. (2) The soda cellulose reacts with carbon disulfide to form sodium cellulose xanthante. (3) The sodium cellulose xanthate is dissolved in dilute caustic soda to give a viscose solution. (4) The solution is ripened. (5) It is extruded into sulfuric acid which regenerates the cellulose, now in the form of long filaments (viscose rayon).

3.1.1.2 Melt Spinning. Melt spinning uses heat to melt the polymer to a viscosity suitable for extrusion into filaments, which are then cooled with air to solidify the filaments. Resins used in this process must be stable at high temperatures to prevent decomposition. Nylon 6 and 66, polyester, and polyolefin polymer chips are all melt spun.

The polymer chips can be melted by numerous methods. The trend is towards melting and immediate extrusion of the polymer chips in an electrically heated screw extruder (See Figure 3-2). Alternately, the molten polymer is processed in an inert gas atmosphere, usually nitrogen, and is metered through a precisely machined gear pump to a filter assembly consisting of a series of metal gauzes interspersed in layers of graded sand (See Figure 3-3). The filtered molten polymer is then extruded at a constant rate, at high pressure, through a (typically) nickel or stainless steel spinneret (see Figure 3-4). The extruded liquid polymer filaments are cooled using an air stream; the solid filaments formed converge at a guide to produce a "spun yarn" or "filament yarn." Some filaments are conditioned before converging (such as steam conditioning for nylon 66).

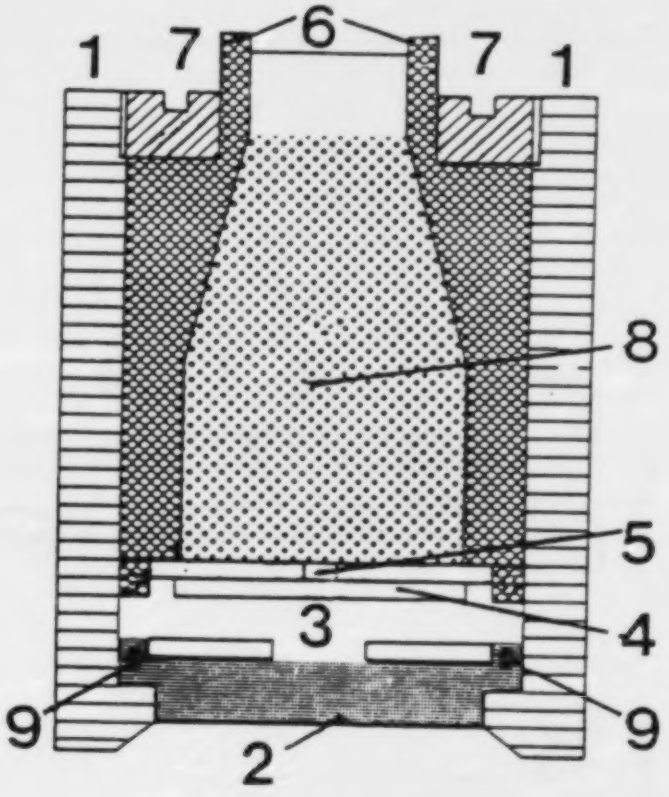
After converging, the fiber is further treated, depending on the desired fiber characteristics. Treatments include drawing, lubrication, crimping, heat-setting, winding, cutting and/or twisting.



Section through an extruder

1 Housing wall
2 Screw
3 Filling hopper
4 Heating elements

Figure 3-2. Extruder



Spinning unit assembly with spinneret

1 Base
2 Spinneret
3 Perforated plate
4 Supporting sieve
5 Sieve round
6 Sand container
7 Screw connection
8 Sand filter
9 Seals

Figure 3-3. Spinning Unit Assembly With Spinneret

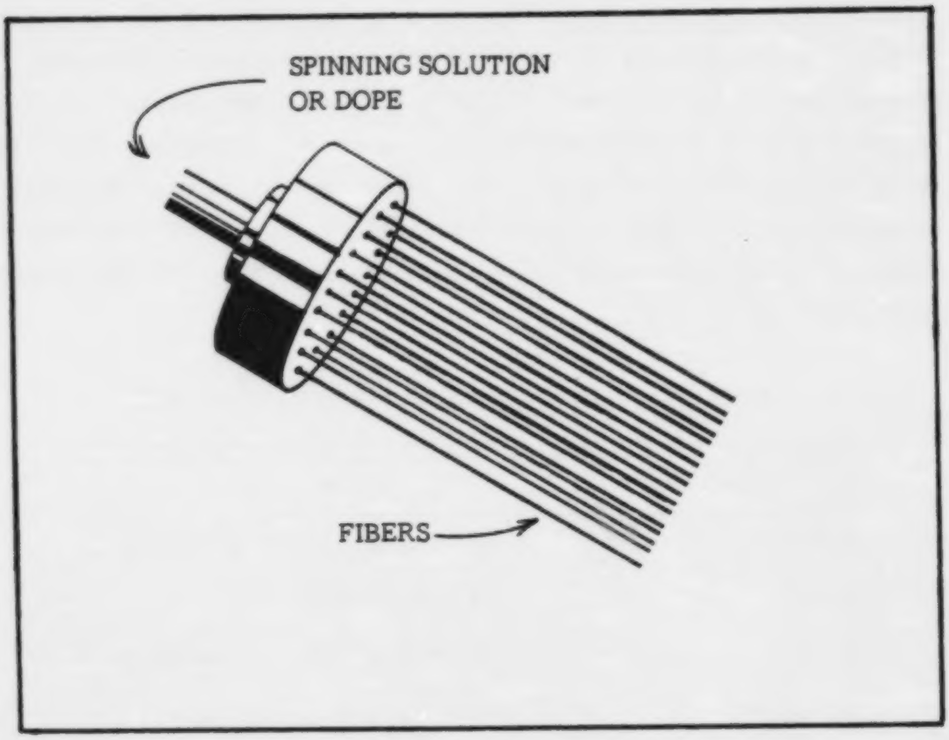

SPINNING SOLUTION
OR DOPE
FIBERS

Figure 3-4. Generalized Spinneret

Input materials (polymers), fibers, and their generic type are listed in Table 3-3 for several representative melt-spun fiber types.

Since melt spinning does not require that the fiber polymer be dissolved in a solvent, but instead be melted prior to extrusion, melt spinning emission rates are considerably slower than those of dry and wet spun fiber processes. Due to the lower volume of volatile organic compounds (VOC) from the melt spinning of synthetic fibers and because VOC's are the most significant air pollutant emitted from these plants, an NSPS for this method of fiber production is not presently being developed.

3.1.1.3 Dry Spinning. Dry spinning involves the use of a solvent to dissolve the polymer chips. The polymer solution is extruded into a zone of heated gas or vapor; the solvent evaporates leaving a solidified filament that is further processed. Figure 3-5 presents a flow diagram for a typical dry spinning process. This process is used for easily dissolved polymers such as cellulose acetate, acrylics, and modacrylics. Higher spinning speeds are possible in dry spinning, and this process is generally used to produce continuous filament yarns.

Table 3-3. INPUT POLYMERS FOR MELT SPINNING[6,8]

Fiber Type	Input Polymer
Nylon	Polyhexamethylene adipamide
Nylon	Polycaprolactam
Nylon	Polyhexamethylene sebacamide
Polyester	Polyethylene terephthalate
Polyester	Poly 1,4 dimethyl dicyclohexyl terephthalate or polyethylene terephthalate
Olefin (polypropylene)	Polypropylene
Olefin (polyethylene)	Polyethylene

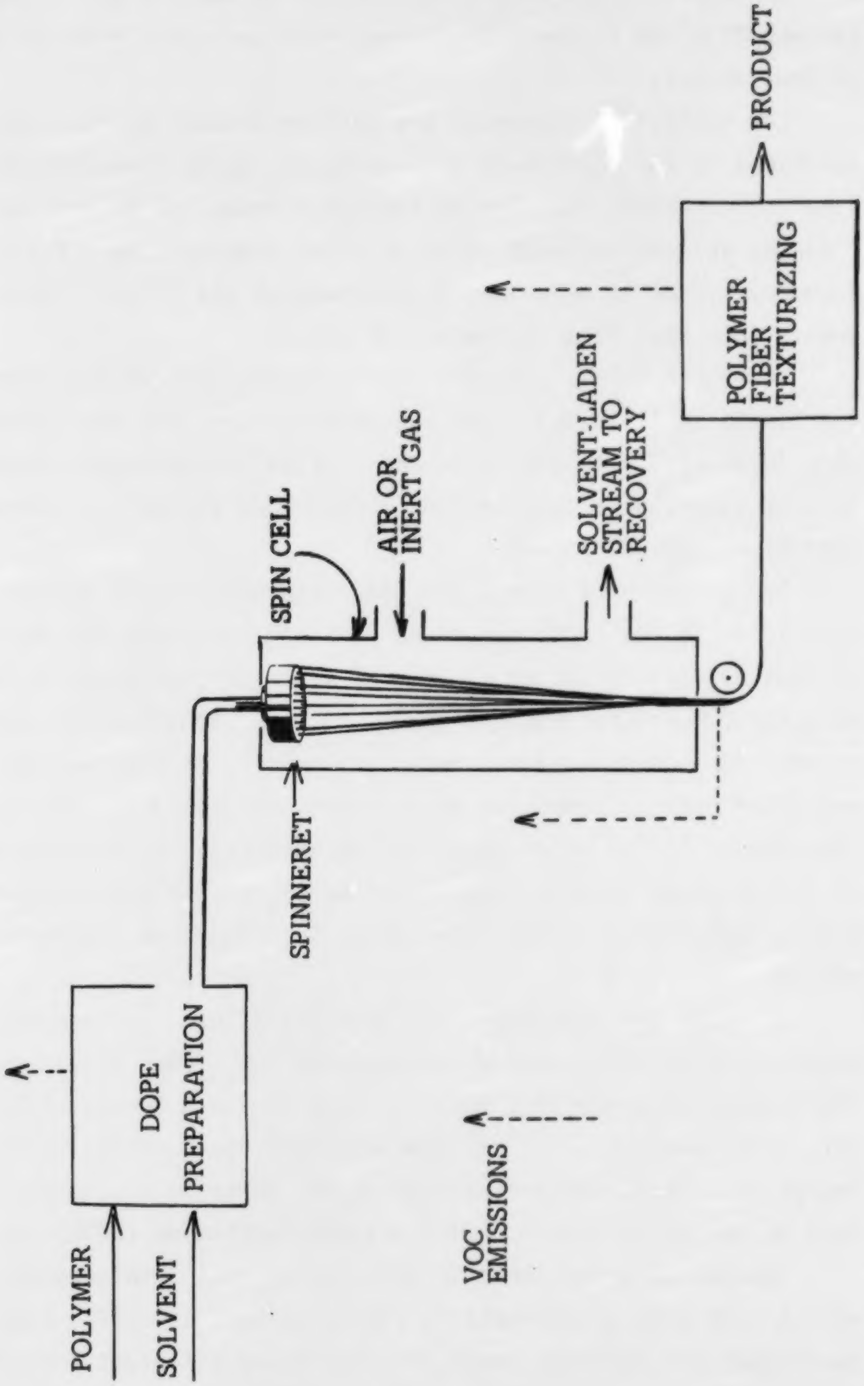

POLYMER
SOLVENT
DOPE PREPARATION
VOC EMISSIONS
SPINNERET
SPIN CELL
AIR OR INERT GAS
SOLVENT-LADEN STREAM TO RECOVERY
POLYMER FIBER TEXTURIZING
PRODUCT

Figure 3-5. Dry Spinning Process Diagram

After leaving the spinneret, the polymer solution passes through a spinning cell which consists of a cabinet about 20 to 30 feet long. Hot, solvent-lean gas enters the cabinet at one end and evaporates the solvent from the filaments. Solvent-rich gas exits from the other end of the cabinet.

The solidified filaments are further treated by the type processes described in the section on melt spinning, again depending on the desired fiber characteristics. Due to the large amount of solvent used, (2 to 3 pounds solvent for each pound of fiber produced) an efficient solvent recovery system is necessary for economical operation. These systems are further described in Chapters 4 and 6.

The fiber types, polymers, and solvents used in dry spinning processes are listed in Table 3-4. The gas used to evaporate the solvent may be air, inert gas (nitrogen or carbon dioxide), superheated steam, superheated solvent vapor, or a combination. Figure 3-6 presents a schematic of a typical dry spinning cell.

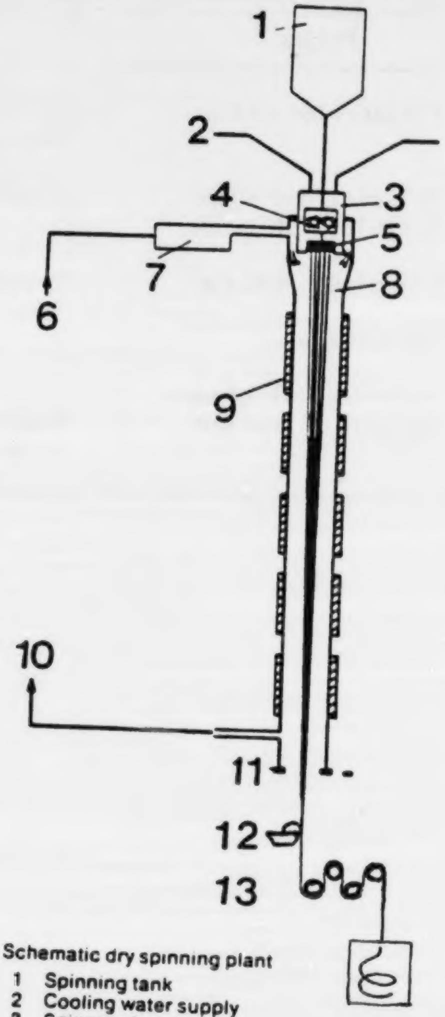
Dry spinning of some fibers generate the largest amounts of volatile organic compounds (VOC) per pound of fiber produced; the dry spinning process as used for other fibers may generate significantly lower VOC emissions, however. Air pollutant emissions from the dry spinning process include volatilized residual monomer, organic solvents, additives, and other organic compounds used in fiber processing. The major emissions are solvent losses which occur during dissolving of the polymer, blending of the spinning solution (dope), filtering of the dope, spinning of the fiber, texturizing of the fiber after spinning, and recovery of the solvent.

3.1.1.4 Wet Spinning. Wet spinning is usually reserved for the manufacture of heavy tow, which requires the slower speeds employed in the downstream processing steps. Heavy tow is a bundle of high denier yarn or filament that is gathered together for handling or packaging. The process begins by dissolving polymer chips in a suitable solvent such as dimethylformamide (DMF), dimethylacetamide (DMAc), or acetone.

Aqueous solutions of zinc chloride or sodium thiocyanate are effectively used as solvents in some processes as well. Each of these individual wet spinning processes, employing different solvents, is

Table 3-4. TYPICAL INPUT MATERIALS FOR DRY SPINNING[6,8]

Fiber	Polymer	Solvent
Acrylic	Polyacrylonitrile	DMF,DMAc Tetramethylene Sulfone
Modacrylic	Polyacrylonitrile/ Polyvinyl Chloride	Acetone
Cellulose Acetate	Cellulose Acetate	Acetone
Spandex	Polyurethane	DMF
Vinyon	Polyvinyl Chloride/ Polyvinyl Acetate	Acetone, Methyl Ethyl Ketone



Schematic dry spinning plant

1	Spinning tank
2	Cooling water supply
3	Spinning head
4	Gear spinning pump
5	Annular spinneret
6	Carrier gas
7	Gas heater
8	Spinning shaft
9	Shaft shell
10	Solvent recovery
11	Orifice
12	Finish application rolls
13	Haul-off rolls
14	Can coiling

Figure 3-6. Dry Spinning Cell

discussed in detail in subsequent sections of Chapter 3. The spinning solution is extruded through spinnerets into a precipitation bath. Precipitation or coagulation ensues by diffusion of the solvent out of the thread into the precipitation bath and by diffusion of the precipitant into the thread. Between the processes employed, there is a wide variation in the percentage composition of the coagulation or precipitation baths and in the temperatures applied. Wet spun filaments will undergo a variety of additional processing steps depending on the end use.

Equipment required for wet spinning includes a solution vessel, a metering pump, a filter, a spinneret, and a coagulant tank. Holding tanks are employed if the products require "aging" of the polymer before spinning. All processes include a recovery system to separate the coagulant and solvent. Table 3-5 lists the fiber types, polymers, solvents, and coagulants used in wet spinning. Figure 3-7 presents a process flow diagram for a typical wet spinning process.

Filaments extruded from the spinneret are further processed in a variety of methods depending on the end use desired. A washing step immediately after extrusion is commonly employed to remove solvent and other impurities. This washing step can occur either continuously or in batches.

The important variables affecting fiber properties in wet spinning are concentration and temperature of the polymer solution (dope) and the composition and characteristics of the spin-bath.

Air pollutant emission points in wet spinning processes that use organic solvents are similar to those of dry spinning, with the solvent losses being generally less than in dry spinning. Wet spinning processes employing solutions of acids or salts emit only small quantities of unreacted monomer, and are therefore relatively clean from an air pollution standpoint.

3.1.1.5 Reaction Spinning. This process may resemble wet or dry spinning, but always involves a continuous chemical reaction within the fiber after extrusion which extends the polymer chain length or provides cross-linking between chains.

This method of fiber formation is similar to that utilized in nature (i.e., silk worms, spiders), and is basically the extrusion of a

Table 3-5. INPUT MATERIALS FOR WET SPINNING[6,8,9]

Fiber	Polymer	Solvent	Coagulant
Acrylic	Polyacrylonitrile	Dimethylacetamide (DMAc)	Aqueous DMAc
		Concentrated Aqueous $ZnCl_2$	Dilute Aqueous $ZnCl_2$
		Aqueous NaSCN	Aqueous NaSCN
Modacrylic	Polyacrylonitrile-polyvinyl chloride copolymer	Acetonitrile DMAc	Aqueous Acetonitrile Aqueous DMAc
		Acetone	Water
Rayon	Cellulose	Aqueous Sodium Hydroxide	Dilute Sulfuric Acid

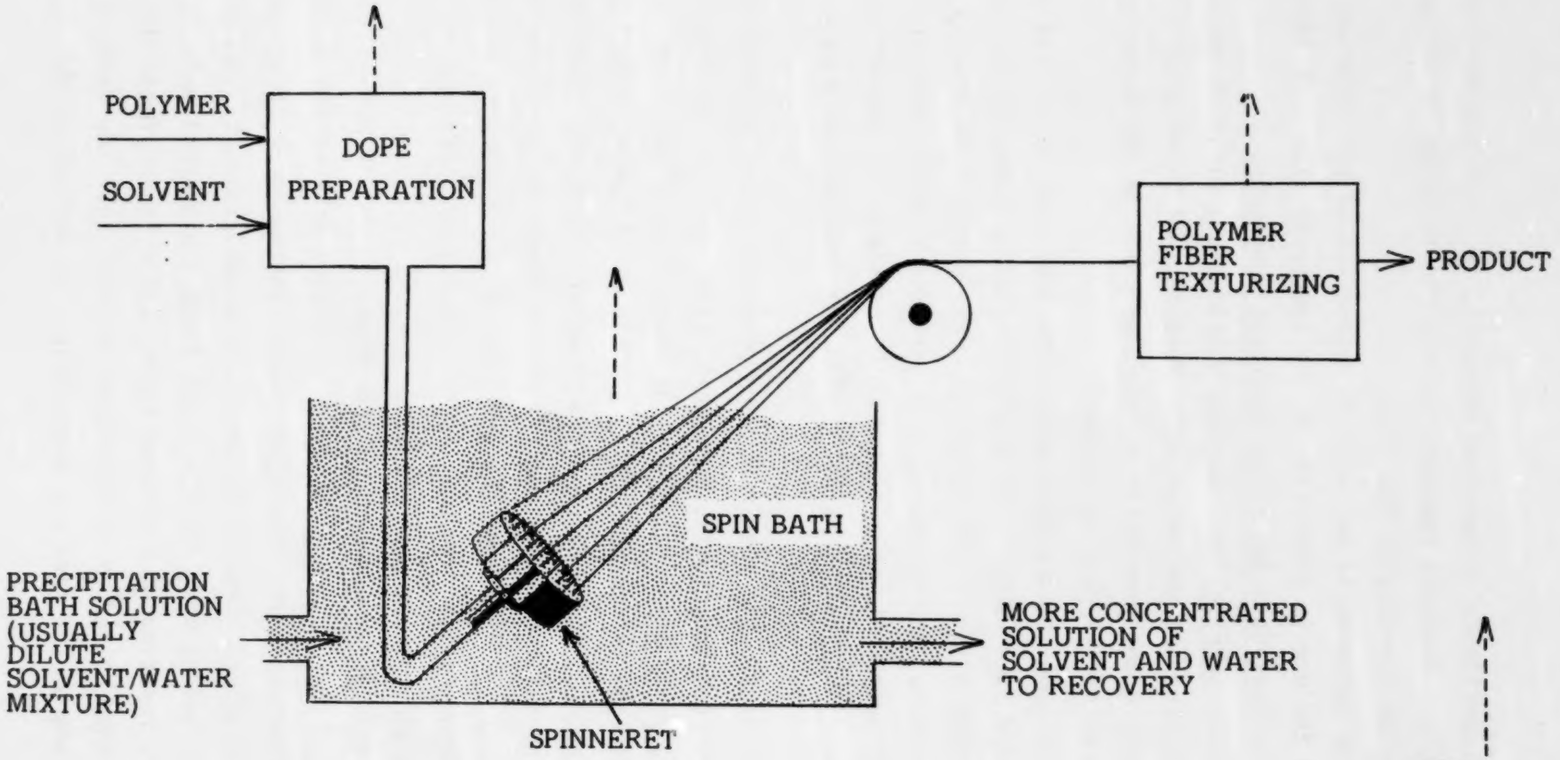

POLYMER
SOLVENT
DOPE PREPARATION
POLYMER FIBER TEXTURIZING
PRODUCT
SPIN BATH
PRECIPITATION BATH SOLUTION (USUALLY DILUTE SOLVENT/WATER MIXTURE)
SPINNERET
MORE CONCENTRATED SOLUTION OF SOLVENT AND WATER TO RECOVERY
VOC EMISSIONS

Figure 3-7. Wet Spinning Process Diagram

pre-polymer (partially polymerized mixture), in which the chemical reaction (polymerization) proceeds to form the final solid polymeric fiber after the spinning of the fiber.

Reaction spinning is not used in production of the major commodity fibers, and its use in production of the specialty fibers is limited.

3.1.1.6 Post-Spinning Fiber Treatment Processes.

3.1.1.6.1 Lubrication. Surface lubrication, plasticizing, and static protection are the three major functions of lubrication. Subsequent handling and processing is improved when the lubricant is added immediately after filament formation.

For melt spun and dry spun yarns, the lubricant is applied before winding onto a spin bobbin. In staple finishing it may be applied by passing through a bath or by spraying. The lubricant is usually added after the washing step in the case of wet spun fibers. Most applications of the lubricant occur at the spinning stage, by contacting the filament immediately after spinning with the lubricant on a ceramic wheel.

Typical antistatic lubricants are polyoxyethylene attached to aliphatic hydrocarbon chains, long-chain alkyl quarternary ammonium salts, hydroxyalkylamine salts of long chain fatty acids, high boiling aliphatic esters, hydrocarbon oils, and fluid silicones. The lubricant is applied as a solution or emulsion in water. Both the composition of the lubricant and the amount applied to the fiber depend on the chemical composition of the fiber and the end use. These lubricants are not liberated in significant amounts in the fiber production process and do not pose an air pollution problem.

3.1.1.6.2 Drawing. Most of the fibers undergo drawing. Drawing, or the stretching of yarn, introduces molecular orientation to the spun fiber and thus produces a stronger fiber. Optimum draw ratios exist for each type of fiber. Drawing of fibers is accomplished by stretching them between two or more rollers: one feeds the undrawn yarn and the next roller, rotating at a greater speed, collects and feeds the drawn yarn to another roller or to subsequent processing. The ratio of the surface speeds of the feed and draw rollers is defined as the draw ratio.

3.1.1.6.3 Fiber modifications. Finally, the fibers may undergo some form of physical modification to produce a specified, marketable product. Modifications include false-twist texturing to produce interfilament cohesion, heat setting or heat relaxation to produce dimensional stability, crimping to add bulk and resilience, and cutting to produce staple products similar to natural fibers. Figure 3-8 presents a diagram of a crimping system.

3.1.2 Production

Projected growth rates and a detailed description of economic conditions in the synthetic fibers industry can be found in Section 9.1.

3.1.3 Location

Nearly all of the man-made fiber production facilities are located in eight states: Virginia, West Virginia, North Carolina, South Carolina, Georgia, Tennessee, Alabama, and Florida. Plant locations, and the type of fiber produced can be found in the subsequent sections dealing with each individual fiber type.

3.2 MANUFACTURING PROCESSES

The synthetic fibers manufacturing industry can generally be characterized as having a stable commodity fiber-producing portion and a relatively dynamic specialty fiber-producing portion, into which new fiber types and production methods are frequently being introduced. Still other solvent-spun fiber types are being produced at bench and pilot-scale levels and may or may not expand to full production (e.g., solvent-spun rayon). In addition, many solvent-spun fiber types are produced in other countries that are not currently produced in the U.S.[2] Clearly, therefore, it would be inappropriate for purposes of this study to describe each one of the almost infinite varieties of fiber types and associated production methods employed within the fibers industry. Rather, there are several basic solvent-spun synthetic fiber processes that can be identified and described that adequately represent most segments of the industry.

All fiber spinning processes share certain fundamental characteristics. Basically, the object is to extrude a liquid or semi-solid polymer with a desired cross section, solidify it, then collect it in a bale or wind it on some type spool or bobbin. In most processes the solid fiber is

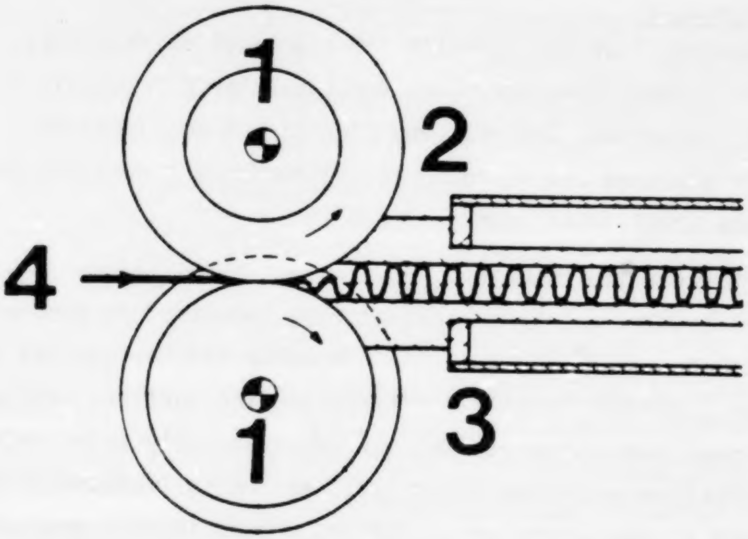


Diagram of a stuffer-box crimping system

1 Rollers for introducing the tow
2 Stuffer box
3 Tempering (only with certain types)
4 Tow

Figure 3-8. Crimping System Diagram

subjected to further processing to enhance its mechanical properties; in others, the fiber is taken up essentially as a finished product. Those broadly identifiable process stages which are common to all solvent-spun synthetic fiber processes include: (1) preparation of the spinning solution. In this stage, polymer is dissolved in an organic solvent, and the solution is blended with additives and filtered to complete the preparation of the dope for spinning. (2) Spinning of the fiber, that is, the actual formation of the fiber filaments. Polymer solution (or dope) is forced or extruded through a device called a spinneret to create the fiber. (3) Processing of the formed fibers. This might include lubrication, washing, drying, heat setting, finishing, or crimping. (4) Solvent recovery. Because of the large amount of solvent used (a pound of polymer is typically dissolved in 2 to 3 pounds of solvent), the economics of the industry require that almost all of the solvent used in dissolving be recovered for reuse. Typically, solvent is recovered most efficiently and economically at the spinning step from the spin-cells or spin baths into which polymer solutions are extruded. About 94 to 97 percent of the solvent used is recycled directly from the spinning step alone. Thus, a primary solvent recovery system is an integral part of all solvent spinning processes.

In addition to the above stages of synthetic fiber production, this chapter will be limited to the production processes that involve the spinning (or forming) of the fiber from a solution of polymer or prepolymer and organic solvent(s). There are a number of fiber types that employ organic solvents in their production; these include acrylic, cellulose acetate, modacrylic, polybenzimizole, spandex, triacetate, vinyon, etc. There are basic similarities in the production sequences for all these fiber types. Three fiber types have been selected for detailed process descriptions, since these types exhibit typical and characteristic production sequences. Acrylic and modacrylic fibers include all fibers consisting of at least 35 percent polymerized acrylonitrile. Cellulose acetate fibers include all cellulosic fibers with an acetylation of 15 percent or greater (includes triacetate). Spandex fibers include all dry and reaction-spun spandex fibers in which the fiber forming substance is a long chain synthetic polymer comprised of at least 85 percent of a segmented polyurethane.

3.2.1 Process Descriptions - Acrylic and Modacrylic Fiber Production

Acrylic fibers are based on the polymerization of acrylonitrile (AN). The monomer AN is derived from propylene and ammonia. Polyacrylonitrile is produced by the synthetic fibers industry with two methods: suspension polymerization and solution polymerization. The polymers formed are generally atactic and have an average molecular weight of 100,000 to 150,000.

3.2.1.1 Forming the Polymer.[6-8]

3.2.1.1.1 Suspension polymerization. The suspension polymerization process is accomplished by suspending small drops of acrylonitrile and comonomers in water using violent agitation and a stabilizer which prevents coalescence of the monomer drops. Polymerization occurs in the presence of a catalyst that is soluble in the monomer. Typically, the reaction is carried out to about 65 to 85 percent completion. Insoluble beads of polymer are formed that are subsequently filtered, washed, refiltered, dried, milled, and stored as powder. Monomers are recovered from the filtration and washing steps and recycled to the polymerization reactors.

3.2.1.1.2 Solution polymerization. A mixture of about 96 percent acrylonitrile and 4 percent methyl acrylate is blended with dimethylformamide, catalysts, and activators; it is then fed into a reactor over a 10- to 20-hour period. The polymerization temperature is maintained at a constant level by means of circulating fluids in the vessel jacket.

Following the polymerization, the reactor effluent is passed to a diluter for mixing with dimethylformamide containing a small percentage of water. The diluted stream is pumped to a horizontal film evaporator operating at reduced pressures. The residual monomer and a portion of the dimethylformamide are stripped from the polymer stream. Pure dimethylformamide is added to the polyacrylonitrile solution leaving the evaporator. The resulting solution generally contains less than 1 percent residual AN monomer.

The solution polymerization method offers the advantage that the polyacrylonitrile can be used directly in the spinning process without the need of drying and redissolving the polymer.

Either batch or continuous reaction modes may be employed, and either wet or dry spinning may be used to form the fibers. Polyacrylonitrile may be spun only from solution, and a variety of spinning solvents are used by industry. Table 3-6 indicates the various methods used domestically to produce acrylic and modacrylic fibers. Additional parameters for wet and dry spinning acrylic fibers can be found in Table 3-7.

3.2.1.2 Domestic Acrylic Fiber Manufacturing Processes.[9-16]

3.2.1.2.1 Producer A. Polyacrylonitrile is fed to a polymer purification system where it is washed to remove any remaining free monomers or catalyst residuals. The purified polymer is subsequently dissolved in a solution of NaSCN. This results in a single phase, 3-component system of sodium thiocyanate, water, and polyacrylonitrile.

The resulting solution is blended and stored. It is then put through a primary filtration operation to remove any suspended solids, and is then sent to a deaeration area. Various additives are incorporated into the mixture to give the fiber product certain desired qualities.

At the spinning stage, dope is extruded into a dilute aqueous NaSCN solution. A washing step removes all traces of solvent from the fiber. The water that is utilized in extrusion, prestretching, and washing steps is routed to a solvent recovery system after it leaves the spin bath.

Following the washing step, the fiber bundle is drawn on rollers to provide molecular orientation and to impart strength to the fibers, and is then dried. A subsequent relaxing operation is employed which allows controlled disorientation of the fiber molecules to enhance dyeability. In the subsequent finishing and tempering stage, a lubricant and antistatic agent is added. A crimp is added to the fibers to give them bulk. The dried product is boxed or baled for storage and shipment.

The solvent recovery system at this company employs multiple effect evaporators to remove the water and concentrate the NaSCN solution exiting the washing stage. After evaporation of the water in the recovery unit, the concentrated NaSCN solution is returned to the dissolving step. The wastewater from the recovery system is routed to a wastewater treatment area where it is treated and disposed of by one of two methods:

Table 3-6. ACRYLIC AND MODACRYLIC FIBER PRODUCTION ROUTES[2,8]

Acrylic Fibers	Registered Trade Name	Typical Chemical Composition of Fiber	Polymerization Medium	Type of Polymerization Operation	Type of Spinning Process	Spinning Solvent
American Cyanamid Company	Creslan	89-90% Acrylonitrile 8% Methyl Methacrylate 2-5% Other	Suspension	Continuous	Wet	Aqueous NaSCN
Dow Badische Company	Zefran	87-90% Acrylonitrile 8% Methyl Acrylate 2-5% Other	Solution	Continuous	Wet	Aqueous $ZnCl_2$
E.I. du Pont De Nemours & Co., Inc.	Orlon	88-91% Acrylonitrile 7% Methyl Acrylate 2-5% Other	Suspension	Continuous	Dry	DMF
Monsanto Company	Acrilan	88-91% Acrylonitrile 8-10% Vinyl Acetate 2-4% Other	Suspension	Continuous	Wet	DMAc
Modacrylic Fibers						
Tennesse Eastman Company Division of Eastman Kodak Company	Verel	37% Acrylonitrile 40% Vinylidene Chloride 20% Isopropylacrylamide 3% Methyl Acrylate	Suspension	Batch & Continuous	Dry	Acetone
Monsanto Company	Elura	76-78% Acrylonitrile 20% Vinyl Acetate 2-4% Other	Suspension	Batch	Wet	DMAc
	SEF	79-81% Acrylonitrile 8% Vinylidene Chloride 9% Vinyl Bromide 2-4% Other	Suspension	Batch	Wet	DMAc

Table 3-7. GENERAL PARAMETERS OF WET AND DRY SPUN ACRYLIC FIBERS[6,7]

	Wet Spinning	Dry Spinning
Percent polymer in dope	20-25	25-35
Pressure across dope filters and spinning branches	7-12 bars	10-15 bars
Number of spinneret holes	3000-60000	300-2000
Haul-off speeds	5-20 m/min	250-500 m/min
Draw ratio	1.2 to 1.6	Variable depending on spin gas temperatures, gas flow rate, and haul-off speeds

(a) a deep well disposal system, or (b) a biological treatment center. Biologically treated waters are disposed of by spray irrigation or are discharged to surface waters.

3.2.1.2.2 Producer B. This acrylic manufacturing facility is comprised of two separate plants with basically similar processing steps. One plant produces polyacrylonitrile homopolymer. The second plant copolymerizes acrylonitrile (AN) and other monomers to produce products with characteristics suited to various end uses. Both plants employ solution polymerization. Polymerization is followed by a vacuum removal step which facilitates recovery of unreacted monomer and thereby reduces acrylonitrile emissions that occur during the spinning operations.

In the spinning process, polymer is dissolved in an aqueous solution of zinc chloride, and is extruded into a coagulation bath containing a dilute zinc chloride/water solution. The coagulated polyacrylonitrile fibers are then washed thoroughly with water in a counter-current bath to remove zinc chloride and other residuals, including monomer. A substantial portion of the unreacted monomer returns with the wash water to be recovered during solvent purification. Monomer loss during spinning and washing, however, is reported to be the major source of process emissions to the atmosphere.[8]

Washing is followed by stretching, drying, crimping, cutting, and baling of the fibers. Selected products are also dyed on-line continuously.

Unreacted monomer is carried over from the polymerization reactor; a portion of this monomer is removed by vacuum stripping of the polymer prior to storage. It is estimated that this vacuum flash step following polymerization releases a majority of the unreacted AN for recovery. The remaining monomer is released from the polymer in the spinning and washing stages. The majority of the unreacted AN, however, is absorbed in the dilute solvent used in the spinning and washing steps; the remaining residual monomer is volatilized and is emitted to the atmosphere. The major source of emissions to the atmosphere during acrylic fiber production at this plant is volatilization of residual unreacted monomer during the spinning and washing operations. Testing by the company has shown that no residual monomer remains in the fiber product. It can therefore be concluded that all residual monomer is released in the spinning, washing, and drying stages. It is believed that all monomer release occurs during spinning and washing of the fibers and that the stretching and drying steps account for only insignificant amounts of monomer release.[8]

There are no direct or add-on emission control systems for reduction of AN emissions applied to the plant spinning facilities. Recovery of a portion of the unreacted AN present in the spinning solution by processing wet-spinning and fiber washing solutions serves as an indirect control method.

The spin bath and fiber handling equipment are partially enclosed in order to increase the air flow rate (e.g., venturi effect) across the polymer and to reduce AN levels in the spinning room. Room air is removed from above the enclosure, and the collected gases are routed to an outlet stack. The partially enclosed spinning area also serves as a means to maintain AN levels below the OSHA limits.

3.2.1.2.3 Producer C. Polyacrylonitrile is formed by suspension polymerization from acrylonitrile. The polymer is filtered, and the resulting slurry is blended and stored. The blended polymer is extruded in the form of noodles, dried in a hot air dryer and stored. Dimethylformamide is subsequently mixed with the pulverized polymer powder and sent to a large blending tank.

At the mixing stage pulverized polymer falls into a mixer. DMF is sprayed onto the pulverized polymer. After being thoroughly mixed, the resulting solution of polymer in DMF falls into a blending tank or storage vessel where the solution is agitated. The spinning dope is pumped through a heat exchanger which heats the polymer solution. The heated solution is filtered through plate and frame filter presses. These filters are hooded to reduce worker exposure to DMF during the time when the filter media is being changed. The used filter media (cellulose) is placed in bins and is repeatedly leached with water. The water used for leaching is sent to the weak feed line of the DMF recovery system.

The spinning solution is then pumped through spinnerets (containing several hundred holes) using a metering device. The head of the spinnerets is kept hot by a steam jacket. Hot nitrogen gas enters at the top of the spinning cell and moves cocurrently with the emerging filaments. The DMF is volatilized or extracted by the nitrogen gas from the emerging filaments as they travel down the length of the spinning cell. Water is applied to the fiber at two points, and the water run-off is drained and processed for recovery of DMF. A set of rolls pulls the fiber away from the spinning cells. Fiber from multiple spinning positions converge to form a single rope or tow which is piddled (deposited) into cans for temporary storage. Air and solvent vapor from the can being filled is ducted to a scrubber, while the air and vapor from filled cans awaiting movement is merely vented to the atmosphere. Before a filled can is moved, a cover is placed on top of the can to reduce occupational exposure to DMF.

The cans containing the spun fiber are transported to subsequent washing and drawing operations. Hot water extracts residual DMF, which is then sent to the dilute DMF (weak stream) recovery system.

Excess water is drained from the tow, and the fibers are crimped. After crimping, the tow is piddled into a creel can. The tow is then cut wet to form staple prior to drying, or is sent directly to a dryer uncut. At the dryer, several tow bands are dried side by side. The steam, solvent vapor, and hot air from the drying operation are exhausted to the atmosphere. After drying, the tow is placed in cartons for shipment or storage.

Work areas are monitored for DMF concentration at numerous points. Samples from these points are fed into three centralized Miran Infrared Gas Analyzers. These points are monitored at a rate of one per minute per analyzer.

DMF and nitrogen, vented from the spinning cell, are routed to a condenser. The nitrogen gas from the condenser is sent back to the top of the spinning cell where it is reheated and again used in evaporating the DMF from the extruded filaments. The condensed solvent is sent to a "strong feed" holding tank (termed "strong feed" because this portion of the recovery stream is very high in DMF concentration). The liquid stream from the strong feed holding tank is next routed to the bottom of a large distillation column where the DMF is recovered. This distillation column separates the solvent from water by driving off the lower boiling-point aqueous phase.

Aqueous DMF streams from the spinning, washing, and drawing operations are sent to a weak feed holding tank (termed weak feed because these liquid waste streams contain low concentrations of DMF). In addition, the gaseous exhaust (emissions) from the end or bottom of the spinning lines is sent to a scrubber. The scrubber solution containing DMF and water is also fed into the weak feed line. The liquid from the weak feed holding tank is vaporized and sent to the top of the distillation column.

Pure DMF recovered from both the strong and weak feed streams from the distillation column is sent through a cooler (heat exchanger) and solvent deionization process. It is subsequently stored in a solvent storage tank along with any make-up solvent needed in the process. The stored DMF is then ready for use in dissolving additional polymer.

The technology utilized by this plant represents the most effective methods and equipment for controlling VOC emissions observed in the industry. Emissions are captured and controlled at more points and areas than is the average or industry-wide practice. Because of its above-average emission control techniques, it is the only facility considered to be operating at better than baseline control as described in this document. Indeed, because it is not an average facility, it forms a basis for the best technological system of continuous emission reduction that "the Administrator of EPA determines has been adequately demonstrated" as required in the Clean Air Act.

A new, modified, or reconstructed facility would not be required to operate at levels demonstrated by this facility in the absence of a new source standard; in fact, the average industry-wide practice is characterized by less stringent capture and control. Therefore baseline control for the dry-spun acrylic fiber model plant will be quantified and described as the expected average practice, and not precisely existing conditions.

3.2.1.2.4 Producer D. This company's modacrylic polymer product is a mixture of two different polymers: a co-polymer of acrylonitrile and vinylidene chloride and a homopolymer of N-isopropylacrylamide.

Polymer powder is stored in silos prior to fiber production. When needed, the polymer powder is dissolved in acetone and filtered. Filtered dope is extruded through spinnerets downward into enclosed cabinets 20 to 30 feet long. Hot, dry air is passed through the cabinet, and acetone solvent evaporates into this heated stream. The solidified fibers exiting the multiple cabinets are collected into a bundle (or tow), then passed through a washing step. After the wash, the fiber is crimped, dried, cut, baled, and stored prior to shipping.

Acetone evaporated at spinning is recovered from the spinning cabinet air via a water scrubber system. Major acetone losses occur as solvent evaporates from the tow as it passes through the washing, crimping, and drying process stages. The volatilized acetone from the drying operation is sent to scrubbers for recovery. Activated carbon beds are used to recover acetone from storage tank vents.

3.2.1.2.5 Producer E. Acrylonitrile is polymerized by the suspension polymerization process to form polyacrylonitrile. The dry polymer (AN) is blended with solvent (DMAc) and delusterants in the mixing stage. The dry polymer is fed (metered) into a mixing area to form a slurry (partially dissolved polymer plus solvent). The slurry is pumped to heaters; as heat is applied, the polymer is completely dissolved. The polymer solution is fed into large holding tanks (from the bottom to reduce air entrainment), and is then pumped to one of several filter presses. Hoods over the presses collect the solvent vapor, and ducts carry the vapor to the roof.

The dissolved and filtered polymer is then pumped through a final, small filter and then to the spinneret jets. The fibers are extruded or spun into a coagulation bath of solvent and water. The coagulation bath is continuously drained to the solvent recovery area. A counter-current water wash flows across the wash area, and into the coagulation bath. This wash water is relatively low in solvent concentration as it first flows over the moving fiber, but gains in solvent concentration as it moves toward and into the coagulation or spin bath. The gain is due to the continuous diffusion of solvent out of the extruded fibers. This spin bath mixture is drained continuously and piped to the solvent recovery area.

The tow bundles then proceed down the process line to the finish area. Typically, this is a bath of lubricants and antistatic agents. Following the finish application, the tow is passed over heated rollers. The steam and vapor released at these points is collected by vent slots in the spinning, washing, and drawing equipment. These vents manifold into a large duct which leads to the roof and atmospheric discharge.

A small percentage of the fiber produced at this company is dyed on the process line at a customer's specifications. The dyeing is performed on selected products at the spinning/finishing/and drawing machines.

After drawing, the fiber leaves the main process line equipment and is fed to a crimping machine. The fiber at this point is dry to the touch. The crimping involves heating the fiber and pressing the fiber tightly against itself, to form wrinkled or crimped fiber. A vacuum duct is installed at the exit of the crimper to cool the fiber and collect the vapor, which is vented to the roof. After this, a conveyor transports and loads the tow into carts for temporary holding and movement to subsequent processing.

The fiber is then transported to a large vessel where heat and pressure are applied. This process is termed stress relieving. The heated and pressurized air and vapors are vented to the atmosphere.

Next, the fiber is put through a recrimping process, since the stress relieving removed most of the crimp induced earlier. As in the first crimping stage, vacuum ducts are installed at the crimper box and underneath the conveyor to cool the fiber and collect the vapors, which are vented to the atmosphere.

A small portion of the unrecrimped continuous tow is baled for shipment at this point. Most of the recrimped tow is carried to a fiber-cutting operation. The cut fiber is then blown into a baling machine. A tamper presses the loose staple into a 500 pound bale, which is automatically weighed, bound, labeled, and covered with plastic wrap.

This type fiber plant using wet-spinning techniques is equipped with a solvent recovery system to recover dimethylacetamide in the solvent/water stream that came from the spinning, washing, and drawing stages. Distillation is used to separate water from solvent in the recovery system. The water from distillation is recycled to the spinning operations and solvent is recycled to dope preparation.

3.2.2 Domestic Cellulose Acetate Manufacturing Processes

There are three companies in the United States that produce acetate fibers at five plant locations. Acetate fiber consumption is nearly equally split between the textile fiber market and the acetate nontextile market, cigarette filtration tow.

Acetate is the second oldest man-made fiber and has become one of the more important fibers in the United States. Even though more than 15 other man-made fibers have since been introduced, none has been able to duplicate the aesthetic properties of acetate at a comparable price.

Cigarette filters made from cellulose acetate tow are widely used. These filters provide the best balance between low price and taste when compared with other materials. Cigarette filtration tow is made from the same cellulose acetate flake as textile fibers; therefore, it has the same percentage of acetylation.[2]

3.2.2.1 Cigarette Filtration Tow.[17-24]

3.2.2.1.1 Producer A. Dried cellulose acetate flakes are stored and dissolved in acetone, and a pigment is added. Dissolving occurs in a closed, agitating mixer. The resulting batches are blended, filtered, and sent through a metering pump which provides a constant flow of the dope to the spinneret head.

Cellulose acetate dope is forced through the spinneret, and the extruded filaments are quenched with air from the scrubber. The solvent evaporates, leaving a filament of cellulose acetate. Acetone-laden air exiting from the spinning cabinet (also called a quench stack) is sent to a cold water scrubber and recycled to the quench stack. This air is conditioned for humidity and temperature before entering the quench stack. The cellulose acetate filaments exit the quench stack and are collected into a bundle or tow. Since cigarette tow is used for filtering, the fibers are smaller, and the holes in the spinneret are smaller and more numerous than those for filament or staple yarn. The post-spinning treatment of the fiber consists of lubrication, crimping, and drying.

All solvent evaporating from the extruded fiber (or filament) in the interior of the spinning cabinet (or quench stack) is sent to a scrubber for recovery. Emissions from the drying process are collected and ducted to carbon beds for acetone recovery. These beds recover 92 to 95 percent of the acetone released at the drying stage. Fugitive emissions from other post-spinning operations are not controlled.

3.2.2.1.2 Producer B. Initially, cellulose acetate resin, which is prepared in-house, is mixed semi-continuously with titanium dioxide (TiO_2) and acetone to make the dope. The resulting batches are blended, then filtered in stages. The final stage is at the spinneret and serves to protect the spinneret, rather than acting as a final filter for the dope. Cellulose acetate dope enters the main header (manifold) and is routed to the spinning machines, which are called metiers. Each metier consists of a group of parallel spinning cabinets. The dope is then metered through a pump and into the spinneret head. The extruded filaments are quenched by room air drawn into the cabinet. The evaporation of the solvent leaves a filament of cellulose acetate, which is collected into a bundle or tow.

The fiber tow travels from the spinning machines to a crimper. Each spinning line has its own crimping equipment. Rollers force the tow bundle into the crimper boxes, while water is sprayed onto the rollers. At this stage, acetone is present in the water, and there is a measurable evolution of solvent vapors. After passing through the crimper the tow band is sent to the dryer, which serves to dry the tow and strip some of the finish oils. The dryers are characterized as a 2-stage system that uses low pressure steam followed by hot air. The cigarette tow dryers exhaust directly to the solvent recovery system, manifolding first to an air conditioning unit with cooling and heating elements. The production process is completed at the finishing and baling operations.

These vapor-laden air streams are manifolded into the solvent recovery system, which leads to carbon adsorption beds. When saturated with acetone, these beds are subjected to steam-desorption; the water-acetone mixture is then distilled and condensed to recover the acetone.

Since a common solvent (acetone) is used in the manufacture of acetate fiber, staple, and cigarette tow, the usual practice to manifold all the solvent-laden air ducts into a common solvent recovery system. The solvent recovery system generally includes one or more units of carbon bed adsorbers with associated air coolers, fan, valves, etc.

Each adsorption unit has three or four carbon bed adsorbers operating on a sequential timed cycle. In normal operation, two or three of these adsorbers would be adsorbing solvent from the solvent-laden air stream, while the third is being desorbed with low-pressure steam. The desorbed solvent and steam passes through a condenser, and then the acetone-water mixture is separated by means of distillation.

3.2.2.2 Cellulose Acetate Yarn.[17-24]

3.2.2.2.1 Producer A. In the cellulose acetate yarn process both continuous and batch cellulose acetate polymerization processes are employed. The spinning process is essentially the same as those previously mentioned, but post-spinning treatment varies. Immediately after spinning, the cellulose acetate filament is wound on bobbins. Some product specifications require a twist be put into the filament, after which the fiber is wound on cores and packaged for shipment. The yarn may also be wound on beams for weaving and packaged for shipment.

All solvent evaporating from the extruded fiber (or filament) in the interior of the spinning cabinet is sent to a scrubber for recovery. No additional solvent recovery is practiced even though the fiber contains up to 20 percent solvent by weight.

3.2.2.2.2 Producer B. Polymer, solvent, and other additives are mixed in a tank by mechanical agitation. The heat of solution aids in the dissolving of certain products. From the mixing tank the dope is sent to successive surge or holding tanks to store the dope before being pumped to filters. Filter presses are not hooded but use normal room air ventilation to remove solvent that has been released at the presses. The filter media is periodically removed from the presses and is steamed in ovens. This mixture of steam and solvent is sent to solvent recovery. All waste polymer is redissolved and sent back to the primary filter presses. The filtered dope is sent to the spinning area.

Portions of dope are drawn from the main header and pumped to the spinning machines (metiers). Each metier consists of a group of side-by-side spinning cabinets; in each cabinet dope is taken off the branch header and passed through individual final filters. The dope is then pumped at a controlled rate through a spinneret at the top of the cabinet. Room air can be pulled in at the top, bottom, or center of the spinning cabinet depending on desired fiber characteristics. The quench air flows cocurrently with the direction of the emerging filaments if it enters at the top of the cabinet, countercurrently if it enters the bottom of the cabinet, and in both directions if it enters the middle of the cabinet.

Filaments emerging from the spinning cabinet are brought together and taken up on a bobbin or pirn. The fiber is subsequently removed from the bobbins or pirns and wrapped on beams or cones for shipment.

As the filament yarn fibers come out of the spinning cabinet, they contain significant residual solvent. Room air surrounding the spinning cabinets contains solvent which has evaporated from the yarn after it leaves the cabinets. Each metier is equipped with a duct for exhaust of vapor-laden air to the solvent recovery system. At sale, the residual solvent content is down to about 1 percent. Therefore, the difference in residual solvent content is emitted into the extrusion (spinning) room or the twisting/beaming/coning rooms (textile area). The extrusion room air is diluted in order to meet/maintain the OSHA worker exposure concentration limits on the solvents.

Improved solvent recovery could be achieved by increasing the concentration of solvent in the room air ducted to the solvent recovery area. However, in order to balance the desire for maximum solvent recovery with the need for protection of workers from solvent exposure, this company has developed a sophisticated system of in-plant air management. This system involves the re-use of plant air from the three basic process areas of the fiber plant. Room air from the dope preparation area (dissolving, mixing, filtering) and room air from the twisting/coning/beaming areas, both of which contain low levels of solvent, are vented (transported) to the spinning room at a predetermined flow rate. The spinning room air is then used to supply the quench air for the spinning cell solvent evaporation. This process air, which contains a high concentration of solvent, is vented together with a fixed amount of spinning room air containing a low level of solvent to the solvent recovery system. To accomplish this air management scheme properly, the plant maintains a slight negative room pressure. The plant carefully monitors this negative pressure as it is an important operating parameter with regard to operation of the solvent recovery system.

The solvents recovered include methylene chloride, acetone, and methanol. A common capture and recovery system is used to collect all the solvent-laden air from the spinning cells, together with a portion of the air from the spinning room. The inlet solvent concentration of the gases at the carbon adsorption system is relatively constant.

The carbon beds are regenerated on a time cycle basis, which is adjusted through analysis of exit stack conditions. Gas chromatographs sequentially monitor all the carbon beds for concentrations of all three solvents. In each recovery unit there are three carbon beds receiving vapor-laden air while one is steaming or regenerating.

There are separate distillation columns for each solvent fraction. The wastewater remaining after distillation contains a small amount of solvent and is sent to the waste treatment plant.

3.2.3 Domestic Spandex Fiber Manufacturing Processes[25-28]

Spandex is a generic name for polyurethane fiber. The Federal Trade Commission defines spandex yarns as "a manufactured fiber in which the fiber forming substance is a long chain synthetic polymer comprised of at least 85 percent of a segmented polyurethane." Urethane is the product of reacting a polyester prepolymer with a diamine cross-linking agent. Between the urethane groups there are long chains which may be polyglycols, polyesters, polyamides, or copolymers of them.

Spandex is produced by two companies in the United States, each employing a different manufacturing process. In some respects, one process is similar to that used for acetate textile yarn, in that the fiber is dry-spun and immediately wound onto take-up bobbins, then twisted or processed in other ways. This spandex manufacturing process is referred to as dry-spinning. The other process is substantially different than any other fiber forming process used by domestic synthetic fiber producers. This manufacturing process is referred to as reaction-spinning.

3.2.3.1 Producer A. This facility employs tetrahydrofuran as the principal raw material; its ring is opened, and the resulting straight chain compound is polymerized to give a low molecular weight polymer. This polymer is then treated with an excess of di-isocyanate. The reactant, together with any unreacted di-isocyanate, is next reacted with some diamine, with monoamine added as a stabilizer. The final polymerization stage is carried out in dimethylformamide solution, and then the spandex is dry-spun from this solution. Thus, this manufacturing process is characterized by use of solution polymerization and dry spinning with an organic solvent. Polymer (or copolymer) is dissolved in solvent, blended with additives, filtered, dry spun, and processed.

Immediately after spinning, spandex yarn is wound onto a bobbin as continuous filament yarn. The yarn is later transferred to large spools for shipment or further processing in another part of the plant. As the fibers are initially wound onto bobbins, they may still contain as much as 5 to 10 percent residual solvent. This residual solvent continuously evaporates into room or building air until 3 to 4 percent (by weight) remains in the fiber.

The major emissions from the spandex dry spinning process are volatilized solvent losses which occur at a number of points in the overall production scheme. Solvent emissions occur during filtering of the spin dope, spinning of the fiber, treatment of the fiber after spinning, and during the solvent recovery process. Figure 3-9 presents a process flow diagram, with emission points shown for this segment of the spandex fibers industry.

Overall emissions from spandex fiber dry spinning are considerably lower than from other dry spinning processes. It appears that the single most influencing factor that accounts for the lower emissions is that, because of the nature of the polymeric material and/or spinning conditions, the amount of residual solvent in the fiber as it exits the spin cell is considerably lower than other dry spun fibers (e.g., 5 to 10 percent versus 15 to 20 percent). This situation may be due to the lower solvent-to-polymer ratio that is utilized in spandex dry spinning (e.g., 1.5 to 2.0 for spandex versus 2.5 to 3.5 for acrylics and acetates). Thus, the multi-stage condensation/distillation system which is used as the primary solvent recovery system serving the spin cell exhaust gas, although basically the same as in other dry spin processes, is overall more efficient in terms of recovery of total solvent used.

3.2.3.2 Producer B. This reaction-spun spandex fiber manufacturer forms their fiber by pumping a polyester prepolymer through multihole

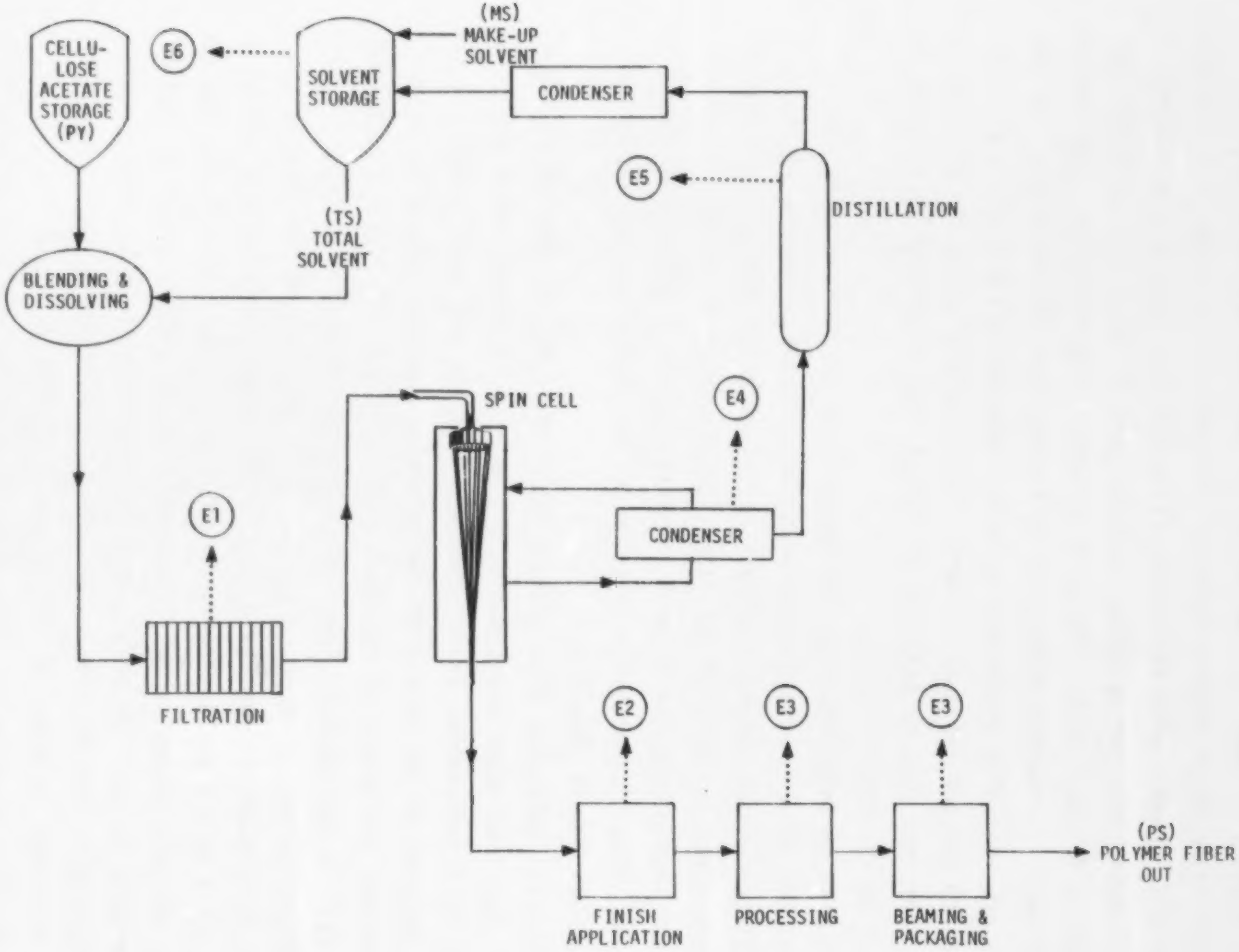

CELLU-
LOSE
ACETATE
STORAGE
(PY)
E6
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
CONDENSER
E5
DISTILLATION
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
SPIN CELL
E4
E1
CONDENSER
FILTRATION
E2
E3
E3
(PS)
POLYMER FIBER
OUT
FINISH
APPLICATION
PROCESSING
BEAMING &
PACKAGING

Figure 3-9. Spandex Fiber Dry Spinning

spinnerets at a constant rate into a bath containing a dilute solution of ethylenediamine in toluene. The ethylene diamine reacts with isocyanate end groups on the resin to form long-chain, cross-linked polyester elastometric fiber. The cross-linking reaction continues for the duration of the process. The fiber is transported from the bath via a heated conveyor belt, through a 2-stage oven where solvent is evaporated. The first stage of the oven is heated with steam coils, and the second stage is heated with infrared heaters. After drying, the fiber is lubricated and collected on tubes for shipment. Fiber sizes range from 10 to 7,000 denier.

Potential VOC emissions are from the spin bath, the heated conveyor belt, and the drying oven. Essentially all air that enters the spinning room is drawn into the hooding that surrounds the spin bath and conveyor belt. This stream is ducted to a carbon adsorption (CA) system. The first stage of the oven is also vented to the carbon adsorber. Due to the relatively low concentration of solvent in the dryer second stage exhaust (e.g., maximum concentration of about 30 ppm solvent), it is not vented to the CA system. The gas streams from the spinning room and oven are combined and cooled in a heat-wheel type exchanger prior to entering the bed.

The carbon is regenerated with steam, and the condensed steam and solvent is sent to solvent recovery. There is some diamine and prepolymer in the aqueous phase of the condensate. After decantation of the toluene, gentle agitation causes the remaining organics to coalese, which simplifies separation from the aqueous phase. The toluene is then purified in a flash distillation column.

The concentration of the inlet stream to the CA unit is maintained at less than 25 percent LEL. The spinning room toluene concentration is around 50 to 60 ppm. The oven exhausts are designed to maintain a maximum concentration of 25 percent LEL.

3.2.4 Other Fibers

In addition to acrylic, modacrylic, cellulose acetate, and spandex fibers, there are numerous organic solvent spun fibers manufactured on a small scale, relative to the commodity fibers. Due to the wide variety of these fiber manufacturing processes, specific products and processes will not be discussed. Table 3-8 lists some of these fibers along with their producers.

3.3 BASELINE EMISSIONS

To determine the impact of possible Federal emission limitations, it is necessary to determine the degree of control imposed by State Implementation Plans and any other control regulations. The baseline control used in the analysis of NSPS impacts it that level that is typical of the industry under consideration. The impacts of an NSPS are then calculated as incremental impacts beyond the impact of the baseline control.

Emission levels for fiber manufacturing facilities in the U.S. were established using state air pollution control information, plant visits, and information submitted to EPA in response to letters of inquiry. These emissions are summarized in Table 3-9. The most significant emissions from these facilities are the solvents used in the spinning of the fiber. Solvent recovery is an integral portion of the manufacturing processes due to the relatively high economic value of the solvent. Solvent-based fiber manufacturing facilities recover between 94 and 98 percent of the total solvent they use for economic reasons, rather than environmental or regulatory incentives. Nonetheless, the industry uses such a large amount of solvent (typically 2 or 3 pounds for each pound of fiber) that the 2 to 6 percent of solvent lost represents a substantial tonnage of VOC emissions.

3.3.1 Acrylic Fiber Production

VOC emissions from the acrylic fiber industry include acrylonitrile, the polymer-forming chemical, and the various organic solvents used to dissolve the polymer (i.e., dimethylformamide, dimethylacetamide and acetone). Processes employing aqueous solutions of acids or salts as polyacrylonitrile solvents have little or no solvent-related emissions (i.e., NaSCN and $ZnCl_2$).

3.3.1.1. Wet Spun Acrylics. Major emission points for wet spun acrylic fibers are the filtration, spinning, washing, drying, and crimping steps where solvent is volatilized into room air and normally vented directly to the atmosphere. A plant of this type represents the processes and air pollution emission control technology currently in use in the wet spinning segment of the acrylic fibers industry. Such a production

TABLE 3-8. TYPICAL SPECIALTY FIBERS

Fiber Trade Name	Manufacturer
Teflon	DuPont
Vyrene	U.S. Rubber Co.
Blue C Elvra	Monsanto
Lycra	DuPont
Spandelle	DuPont
Glospun	Globe Mfg. Co.
Vinyon	-
Polybenzimidazole	Celanese
Nomex	DuPont
Kevlar	DuPont
Numa	-
Kynol	Carborundum

Table 3-9. BASELINE EMISSIONS FROM TYPICAL SYNTHETIC FIBERS PLANTS

Type of Fiber	Baseline Emission Rate (kg/1000 kg fiber)	Fiber Produced 1980 (Thousand Megagrams)	Fiber Produced 1980 (Million Pounds)	Estimated Emissions 1980 (Megagrams)	Estimated Emissions 1980 (Million Pounds)
Wet Spun Acrylic & Modacrylic	40	129[a]	284[a]	5,160	11.4
Dry Spun Acrylic	45	125[b]	275[b]	5,625	12.4
Dry Spun Modacrylic	140	20[c]	44[c]	2,800	6.2
Cellulose Acetate Cigarette Filtration Tow	120	174[d]	383[d]	20,880	46.0
Cellulose Acetate Textile Yarn	145	146[e]	322[e]	21,170	46.7
Dry Spun Spandex	10	4.5	10	45	0.1
Wet (Reaction) Spun Spandex	150	4.5	10	675	1.5
Total		603	1,328	56,355	124.3

[a] Chapter 9, Reference 23; estimated 90 percent capacity utilization.

[b] Chapter 9, Reference 23; less modacrylic capacity; estimated 90 percent capacity utilization.

[c] Chapter 9, Table 9-7; estimated 90 percent capacity utilization.

[d] Chapter 9, Table 9-31; 1979 production plus 5 percent estimated increase.

[e] Chapter 9, Table 9-32; 1979 production plus 2 percent estimated increase.

or process sequence is considered as "baseline control." The process lines are essentially open to room air. Ventilation hoods are located above the spinning and washing areas and at other major processing points. The existing ventilation systems are designed around high air flow rates with little emphasis on enclosures to reduce air volume flow.

There are no VOC emissions from nonorganic solvent wet spinning processes (i.e., aqueous solutions of acids, NaSCN and salts, $ZnCl_2$) resulting from the volatilization of solvent. Acrylonitrile emissions from these processes would be essentially the same as the organic-based wet spun solvent process.

3.3.1.2 Dry Spun Acrylics. Sources of emissions include filtering, spinning, washing, drawing, steaming, and drying. Air pollution emissions from dry spun acrylic fiber production include residual monomer (acrylonitrile) and solvent (dimethylformamide).

3.3.1.3 Dry Spun Modacrylic. The manufacturing stages are quite similar to those of dry spin acrylic fibers. The major baseline emissions from this dry spinning process are volatilized solvent losses which occur at a number of positions in the overall production scheme. Solvent emissions occur during dissolving of the polymer, blending of the spinning solution (dope), filtering of the dope, spinning of the fiber, processing of the fiber after spinning, and during the solvent recovery process.

3.3.2 Cellulose Acetate

3.3.2.1 Cellulose Acetate Cigarette Filtration Tow. The post-spinning fiber processing steps in domestic plants are typically open to room air; the exception is the dryer, from which emissions may be controlled. Since the fibers as spun contain as much as 20 percent residual solvent, significant amounts of solvent are volatilized from the fibers into the room air. These fugitive emissions are as high as 85 kg VOC per 1,000 kg of dry polymer produced.

3.3.2.2 Cellulose Acetate Textile Yarn. Filtration, spinning, and post-spinning stages are the significant sources of VOC emissions in the manufacture of cellulose acetate textile yarn. In the process sequence, the stages including and preceding spinning are identical to those of acetate filtration tow. Immediately after spinning, acetate textile yarn is wound onto a bobbin as continuous filament yarn, with no further treatment. The yarn is subsequently transferred to larger spools (beams or cones) for shipment or further processing (twisting or winding, for example) in another part of the plant. A portion of the yarn is sold directly in packages from the spinning machine.

As the fibers are initially wound onto bobbins, they may still contain as much as 20 percent residual solvent. This residual solvent continuously evaporates into room or building air until equilibrium is reached at around 1 percent (by weight) residual solvent. On an industry-wide basis, these fugitive emissions are about 150 kg VOC per 1,000 kg of polymer processed.

3.3.3. Existing Regulations

3.3.3.1. State and Local Regulations. There are no State or local emission regulations which apply specifically to the production of man-made fibers. Of the eight States that contain almost all man-made fiber production facilities, most employ a ceiling or guideline regulating VOC's which is similar to California's Rule 66. Two of these eight States have little or no volatile organic compound emission control regulation whatsoever. These eight States are listed below with their general VOC regulations.

Alabama: Volatile organic compound emissions shall be limited to 40 pounds/day or 8 pounds in any 1 hour, or emissions shall be reduced by 85 percent.

Florida: No person shall store, pump, handle, process, load, unload, or use in any process or installation volatile organic compounds or organic solvents without applying known and existing vapor emission control devices or systems deemed necessary and ordered by the department. All persons shall use reasonable care to avoid discharging, leaking, spilling, seeping, pouring, or dumping VOC's or organic solvents.

Georgia: There are no general regulations concerning VOC emissions in Georgia except for certain designated industries. Synthetic fiber manufacturing is not included in this group of industries.

North Carolina: Volatile organic compound emissions are regulated similarly to the restrictions of Rule 66 in California (anything in excess of 40 pounds/day must be reduced by 85 percent).

South Carolina: No applicable VOC regulations.

Tennessee: General VOC regulations state that in a county of over 100,000 people all new sources must not emit over 100 tons/year, otherwise the source would be subject to the lowest achievable emission rate (LAER). If a county's population is less than 100,000, a source must use reasonable and proper controls.

Virginia: The only effective VOC regulations are those that apply to northern Virginia. These are similar to California's Rule 66.

West Virginia: There are no effective VOC regulations, except for control of noxious odors.

In summary, State regulatory agencies currently do not impose VOC limitations which significantly affect man-made fiber spinning. Although numerous control devices exist for capture and recovery of organic solvents and other volatile organic compounds released in spinning operations, these are operated mainly for worker protection reasons and for economic purposes.

3.3.3.2 OSHA Regulations. Organic solvents used in the manufacture of acrylic and cellulose acetate fibers are controlled by existing OSHA regulations for exposure within the working area. Acrylonitrile, the monomer used in acrylic fiber production is also governed by these regulations. Table 3-10 lists these VOC's and their corresponding Threshold Limit Values (TLV) for an 8-hour day.

In order to meet these regulations most fiber producers (especially acrylic) include additional ventilation capacity and capture systems to reduce worker exposure. In some instances it is economically feasible to route this additional solvent-laden gas to the solvent recovery area, thereby increasing the percentage of solvent recycled.

Table 3-10 OSHA LIMITS FOR EXPOSURE TO SOLVENTS AND OTHER COMPOUNDS USED IN THE MANUFACTURE OF ACRYLIC AND CELLULOSE ACETATE FIBERS

Agent	TLV/TWA 8-hour day
Acetone	1,000 ppm
Dimethylacetamide (DMAc)	10 ppm
Dimethylforamide (DMF)	10 ppm
Acrylonitrile	2 ppm

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4.0 EMISSION CONTROL TECHNIQUES

4.1 INTRODUCTION

As identified in Chapter 3 of this document, volatile organic compounds (VOC's) are the most significant air pollutants released to the atmosphere during the manufacture of organic solvent spun fibers. Due to the economic value of solvents used in the synthetic fibers industry, capture and recovery of these solvents is an integral portion of the manufacturing process.[1] Presently, domestic synthetic fiber manufacturing processes recover 94 to 98+ percent of the solvents used in fiber formation. Therefore, solvent capture and recovery techniques presently employed in the synthetic fibers industry are also indirect methods of VOC air pollution emission control. In most cases, capture systems with subsequent solvent recovery are applied only during the actual spinning of the fiber; the majority of VOC emissions from the pre-spinning (solution mixing and filtering, etc.) and post-spinning (washing, drawing, crimping, heat setting, and drying, etc.) operations are not recovered for reuse. Potential for additional solvent recovery and further VOC emission control exists at these locations in the manufacturing process.

There are five basic techniques employed in the synthetic fibers industry to recover solvent from wet, dry, and reaction spinning processes:

1. Gas Absorption
2. Gas Adsorption
3. Condensing
4. Distillation
5. Enclosure and Capture Systems.

These collection devices recover solvent from spinning cell solvent-laden air during dry spinning and recover solvent from the spin bath and wash water in wet spinning. These streams contain high concentrations of solvent and therefore possess the greatest potential for economic and efficient solvent recovery.

In addition to the capture and recovery of solvent during the actual spinning step, many wet, dry, and reaction spinning operations incorporate hoods or complete enclosures as capture systems along pre-spinning and post-spinning process lines to prevent worker exposure to solvent and unreacted monomer. Quantities of solvent released during these portions of the manufacturing process are much smaller than those released during the actual spinning of the fiber, and are usually vented to the atmosphere. Recovery of solvent at these processing points is usually not attempted because of the relatively high air flow rates necessary to reduce solvent and monomer concentrations around the process lines to acceptable concentration levels determined by limits on worker exposure.

A detailed description of the solvent capture and recovery techniques presently employed in the synthetic fibers industry is presented below. Because recovery process techniques may be specific to fiber type or spinning method, a discussion of the different recovery methods for each of the various spinning operations will be treated separately. In addition to these methods of VOC emission control, a discussion of other techniques available to the synthetic fibers industry to control VOC emissions will also be presented.

4.2 GAS ABSORPTION EQUIPMENT[2,3]

Absorption equipment is designed to promote interphase diffusion between the solute gas and the absorbent liquid. The mechanism governing absorption techniques is believed to occur via a physical interaction dissolving the solute gas into the absorbent, or a chemical reaction between the two phases. Absorption requires a high degree of exposure-surface-area to guarantee good contact between the vapor-laden gas and the liquid absorbent. The efficiency of an absorber unit is dependent upon the rate of mass transfer which takes place between the gas and the liquid. Characteristics of the liquid absorbent such as volatility and viscosity, as well as solubility properties of the solute gas in the liquid absorbent, significantly contribute to absorber efficiency.

In an effort to maximize the effectiveness of absorption techniques in reducing or recovering process stream VOC emissions, a variety of absorption equipment has been designed to achieve good contact between the gas and the absorbent. These units are typically identified as packed towers, plate or tray towers, spray chambers, and venturi absorbers.[4]

4.2.1 Packed Towers[2,4]

It has been shown that systems of this type achieve high rates of absorption. Packed tower adsorbers are vertical columns filled with an irregularly-shaped packaging material. A liquid absorbent is introduced near the top of the column through liquid distributors and is sprayed or otherwise distributed over the packing to wet the entire surface. Absorbent liquid flows downward through the column in a direction countercurrent to the solute gas which is introduced at the bottom of the tower. This solid-liquid medium provides for a large surface-to-volume ratio of absorbent to absorbate, which in turn determines the effective contact area for the solute gas. Consequently, the concentration of the solute gas stream decreases as it rises through the column due to the high absorption rate of the gaseous constituents onto the liquid absorbent, which is distributed on the surface of the packing material. Fresher absorbent is available for the more dilute gas stream in a zone just above any given contact area. Figure 4-1 presents a schematic diagram of a packed tower.

When the active adsorption sites of the solid-liquid medium become saturated with solute gas constituents, the system is defined as having reached load point. Size and operating characteristics of a packed tower are basically derived from four design parameters: column diameter, pressure drop, number of transfer units, and the height of the transfer unit.

4.2.2 Plate or Tray Towers[2,4]

Plate or tray towers are designed to provide contact between the solute gas stream and liquid absorbent through a series of plates (trays) arranged in a step-like manner. Bubble-cap plate towers are the most common example of plate-type absorbers. Typically the plates permit deposition of the gas onto the liquid surface through plate

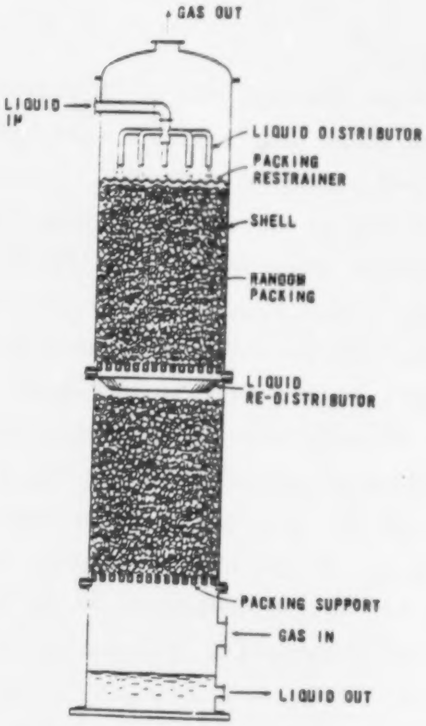

GAS OUT
LIQUID IN
LIQUID DISTRIBUTOR
PACKING RESTRAINER
SHELL
RANDOM PACKING
LIQUID RE-DISTRIBUTOR
PACKING SUPPORT
GAS IN
LIQUID OUT

Figure 4-1. Schematic Diagram of a Packed Tower[3]

openings covered with caps. Vapor rises through the plate apertures and exits the caps via peripheral slots which direct the gas onto that portion of the plate which is immersed in liquid. Liquid travels through the column in a cascade fashion by entering the top of the tower, flowing across each plate, and down through each series of plates by way of downspouts. Design parameters for plate or tray towers include: gas velocity, temperature, liquid flow patterns, plate spacing, and depth of liquid on the plate. The number of stages necessary to theoretically remove a given percent of the solute gas from the gas stream is divided by the actual number of plates required for the same system in order to determine the overall efficiency of the tower. Figure 4-2 illustrates the design of bubble-cap tray towers.

4.2.3 Spray Chambers[2,4]

A more simplistic approach to accomplishing interphase contact between the solute gas and the liquid absorbent is exemplified by spray chamber absorbing units. Typically, this device consists of an empty chamber equipped with a series of nozzles which spray a liquid over the cross section of the vessel as the gas passes through the spray. The size of the spray droplets affects the efficiency of this type absorber by determining available surface area for contact between the two phases. Spray nozzles can be selected to provide droplet sizes ranging from 500 to 1,000 microns. Solubility characteristics of the solute gas-absorbent mix will also contribute to percent removal or recovery values for process stream pollutants.

4.2.4 Venturi Absorbers[2,4]

Venturi absorbers, like spray chambers, can be used to reduce gaseous emissions. The venturi type absorber accomplishes interphase contact between the solute gas and the liquid absorbent by introducing the gas and the liquid into the throat of the venturi at different velocities. High gas velocities required by the venturi serve to increase the effective collision between the gas and liquid streams. Power requirements necessary to provide such high velocities can be large, due to the fact that energy is dissipated in the form of a

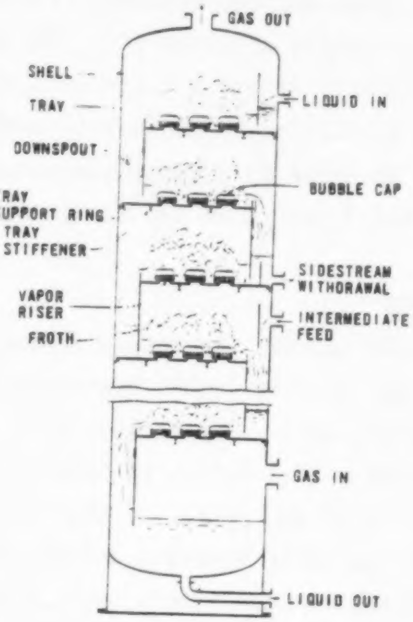

GAS OUT
SHELL
TRAY
LIQUID IN
DOWNSPOUT
BUBBLE CAP
TRAY SUPPORT RING
TRAY STIFFENER
SIDESTREAM WITHDRAWAL
VAPOR RISER
INTERMEDIATE FEED
FROTH
GAS IN
LIQUID OUT

Figure 4-2. Schematic Diagram of a Bubble-Cap Tray Tower[3]

pressure loss. Venturis have the advantage of obtaining a high degree of liquid-gas mixing, but have the disadvantage of short contact times. High velocity requirements can also generate an entrainment problem, which usually necessitates the use of a mist eliminator downstream in the system.

4.2.5 Gas Absorption Equipment as Currently Employed by the Synthetic Fibers Industry[5-11]

4.2.5.1 Dry Spun Acrylic Fibers.[1,12] Dry spinning of acrylics is performed by extruding a solution of polymer in an organic solvent (usually dimethylformamide) through a spinneret plate into a spinning cell. A column of hot inert gas that is above the boiling point of the solvent is circulated in the direction of the emerging spinning solution. The solvent evaporates into the spinning cell leaving a solidified filament. The solvent-laden gas stream is routed to a wet scrubber. Approximately 90 percent of the total solvent introduced into the system is recovered at the spinning cell. Capture and recovery of solvent from the spinning cell quench gas serves as an indirect means of controlling VOC emissions.

At the exit of the spinning column the fiber contains from 15 to 30 percent solvent by weight. Most of this residual solvent is removed from the spun fiber in the subsequent washing, drawing, crimping, and drying process stages. Some residual solvent remains in the final product. Partial enclosures are used around pre- or post-spinning stages to capture volatilized solvent so that OSHA standards for occupational exposure in the work area can be met. These enclosures are vented to the atmosphere; no attempt is made to recover or control these emissions via conventional air pollution control equipment.

4.2.5.2 Dry Spun Cellulose Acetate.[1,12] Recovery of solvent from the spinning of cellulose acetate fibers is accomplished in the same manner as solvent recovery from dry spinning of acrylic fiber. Air entering at the top of the spinning cabinet flows cocurrently with the direction of the extruded filaments and removes volatilized solvent (acetone) from the acetate filaments. The air stream or quench gas, containing high concentrations of acetone, exits the spin cell and is sent to a solvent recovery device. When wet scrubbing is used as the recovery device, the acetone in solution with water is transported to a distillation column where the acetone is separated for recovery and reuse.

As the fiber exits the spin cell it contains as much as 20 percent acetone by weight. The remaining post-spinning processes are usually uncontrolled, and residual acetone in the fiber is allowed to evaporate into the room air. Because the TLV for acetone is relatively high, and stringent precautions are not necessary to minimize worker exposure, little or no attempt is made to capture and remove fugitive acetone emissions along the other portions of the process line. Instead, general room air ventilation is used to maintain the solvent concentration at acceptable levels. Emissions from the filtering of the dope prior to spinning are also uncontrolled.[13]

4.2.6 Gas Absorption Equipment Performance

VOC control efficiencies of scrubbers are known to exceed 99 percent.[4] Absorption is highly dependent upon solubility for effectiveness. High solubilities tend to reduce the column's liquid-gas ratio by minimizing the required liquid flow rate for a given efficiency. Concentration of the exhaust stream influences the selection of absorber design. If very low concentrations of a highly soluble VOC are directed to the absorber, the size of the tower can be relatively small and gas-liquid throughputs can be optimized. In the case of highly concentrated streams of a fairly insoluble material, long residence times and/or larger towers are necessary to promote contact. Acetone, DMF and DMAc are infinitely soluble in water, thus a favorable equilibrium can be established that will promote effective VOC removal efficiencies.

The total emission rate of the vapor-laden gas stream, more than any single parameter, governs the size of the absorber unit.[14] Temperature is also an important variable to be considered in the design of an absorber. The gas volume affects the size of the collector regardless of the method of absorption chosen. The exhaust gas flow rates and concentrations of the solvents at synthetic fiber plants make VOC scrubbing using water as the absorbent a practical control technique.

Packaged towers, plate towers, and spray chambers are the types of absorption devices most effective for VOC collection. However, there are advantages and disadvantages for each system, and final selection should be based on the following comparative information:[2]

- if the gases tend to be corrosive, as are DMF and DMAc, packed towers are generally less expensive than plate towers;
- if throughput is the same, packed towers will exhibit smaller pressure drops than plate towers;
- liquid "hold-up" is usually less in a packed tower;
- packed towers tend to plug more readily than do plate towers;
- plate towers are better suited for continuous temperature variations;
- spray chambers demonstrate a lower absorption efficiency than both packed and plate towers.

4.3 GAS ADSORPTION EQUIPMENT[15-17]

Gas adsorption equipment (primarily carbon beds) has been used for solvent recovery by the synthetic fibers industry and other industries for many years. In general terms, the principle behind adsorption as it applies to the synthetic fibers industry may be described as follows: the "activated" carbon constitutes the adsorbent, and the organic solvent that is removed from a gaseous stream is referred to as the adsorbate. Adsorption occurs at the gas-solid interface of the adsorbent. The mechanism of adsorption is believed to be a combined effect of: physical adsorption of the adsorbates without a chemical change; Van der Waals forces between the carbon surface and the gas that acts to form layers of gas molecules; and capillary action that occurs in the fine pores of the absorbent material. Adsorption is an exothermic process, and cooling may be necessary to prevent excessive heat buildup.[17]

There are several variables which affect the performance of carbon adsorbers, and most are related mathematically to the adsorptive capacity of the carbon. Adsorptive capacity defines the weights of adsorbate that can be retained on a given weight of carbon, and is expressed below:[18]

$$\text{Adsorptive Capacity} = \frac{Vm}{T \log (Co/Ci)}$$

where, adsorptive capacity = $\frac{\text{grams of adsorbate}}{\text{grams of adsorbent}}$

Vm = liquid molar volume of adsorbate at normal boiling point

T = absolute temperature

Co = concentration of adsorbate at saturation

Ci = initial adsorbate concentration into adsorber.

The liquid molar volume of an individual adsorbate is related to the individual molecular weight and density of the solvent at its boiling point. The greater the Vm of the adsorbate, the higher the molecular weight and boiling point. In other words, carbon generally has a greater adsorptive capacity for higher boiling point and higher molecular weight solvents. The removal of solvents by physical adsorption is practical for adsorbates with molecular weights over 45.[19]

Adsorption equipment is designed to collect and retain vapors on the adsorbent material until the absorbent becomes saturated. Adsorber units can allow for either regeneration (desorption) or disposal of the used adsorbent material. Nonregenerative systems are units that do not reuse spent absorbent and require that the adsorbent material be removed for regeneration or incineration.

The adsorption cycle takes place in two stages: adsorption and regeneration. Initially, the adsorption rate of gaseous vapors is rapid and complete; but as the adsorbent is saturated, collection efficiency of the system decreases. Regeneration requires that a hot gas, usually steam, be passed upward through the bed, which drives off adsorbed compounds. Following regeneration but prior to the control system being put on-stream, cooling and drying of the bed is necessary due to the temperature and water content of the adsorbent. Insufficient cowling and drying will result in reduced efficiency. If the desorption feature is an integrated component of the solvent recovery system, then the vapor-laden effluent is condensed and separated by decantation or distillation. Figure 4-3 shows a typical carbon adsorption process employed in the synthetic fibers industry.

Adsorbers can have fixed, moving, or fluidized beds, and can be opened either vertically or horizontally. The simplest adsorber design is a vertical cylinder containing a fixed bed adsorbent sandwiched

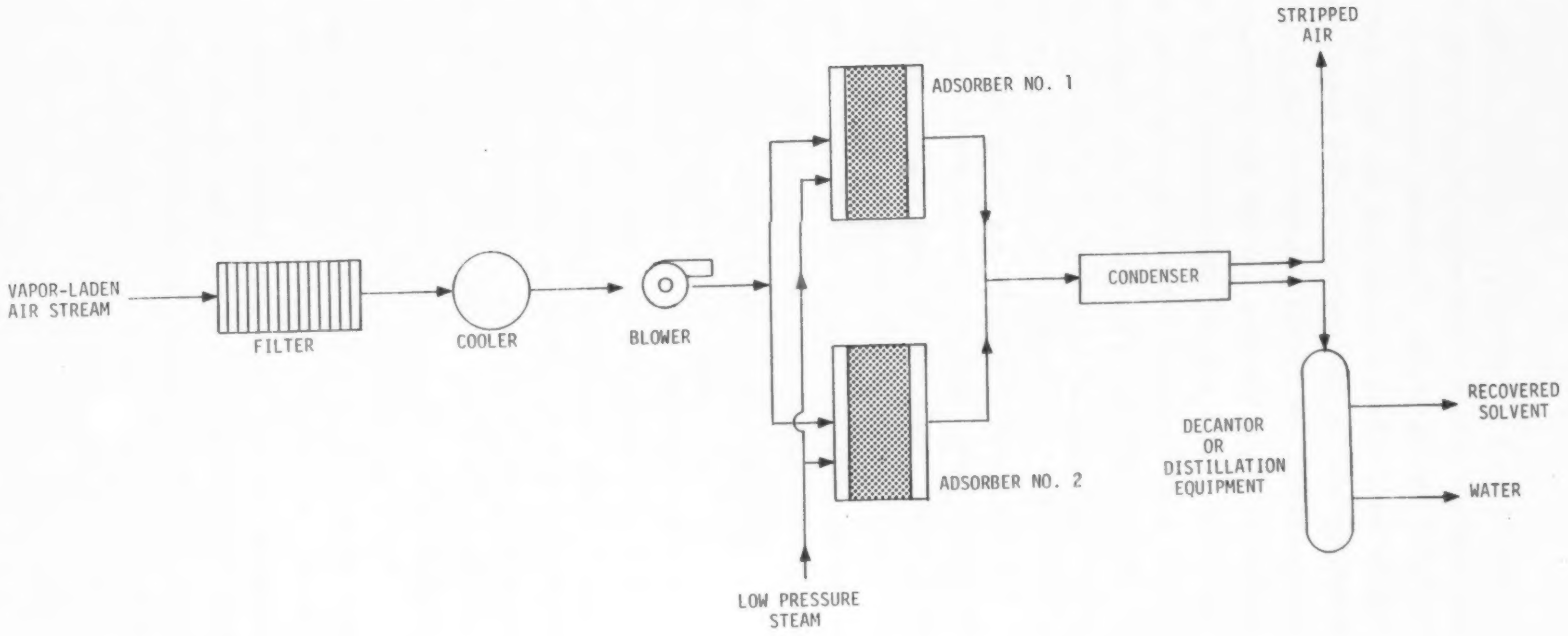

VAPOR-LADEN AIR STREAM
FILTER
COOLER
BLOWER
ADSORBER NO. 1
ADSORBER NO. 2
LOW PRESSURE STEAM
CONDENSER
STRIPPED AIR
DECANTOR OR DISTILLATION EQUIPMENT
RECOVERED SOLVENT
WATER

Figure 4-3. Carbon Adsorption Process

between screens. Typically, fixed bed adsorbers are a two-unit system; one adsorber cleanses the vapor-laden stream, while the second bed undergoes regeneration. Three-bed adsorber units usually employ one bed for adsorbtion, a second bed for regeneration, while the third bed undergoes cooling and drying. Figure 4-4 illustrates three different configurations for carbon adsorption that could be employed in the synthetic fibers industry. Fixed bed adsorbers may be designed in a cone shape. This type of construction allows for a large adsorbent surface area exposure. Higher gas flow rates at lower pressure drops are accommodated by cone-shaped units in contrast to a flat bed system using the same total weight of adsorbent.[17] Horizontal beds are also employed, with the carbon beds enclosed in a cylinder.

A moving bed configuration passes activated carbon through an adsorption zone. Due to fresh adsorbent continually being fed into the adsorbing zone, moving bed adsorbers demonstrate higher collection efficiencies than stationary bed systems. Disadvantages include wear on moving parts, more rapid attrition of adsorbent, and higher steam requirements for desorption due to shorter carbon beds.[17]

4.3.1 Applicability to The Synthetic Fibers Industry

4.3.1.1 Dry Spun Cellulose Acetate and Triacetate.[6-11]

Three fiber producers are currently employing carbon adsorption as a means of recovering solvents from their cellulose acetate production lines. In one case, volatilized solvent (acetone) from the drying process is sent to carbon beds for acetone recovery. Steam is used to strip the solvent from the carbon beds, then the condensed steam and acetone is distilled. Approximately 92 to 95 percent of the acetone released at the drying stage is recovered by the carbon adsorber.

In another case, acetone-laden air from the spinning cells discharges into several carbon beds. Again, steam is used to strip the acetone from the carbon beds. Once stripped, the acetone-laden stream is condensed, cooled, and pumped to stills where the acetone is separated from the solution and recovered for reuse. It is reported that this system routinely achieves 98 percent efficiency after capture of the vapor.

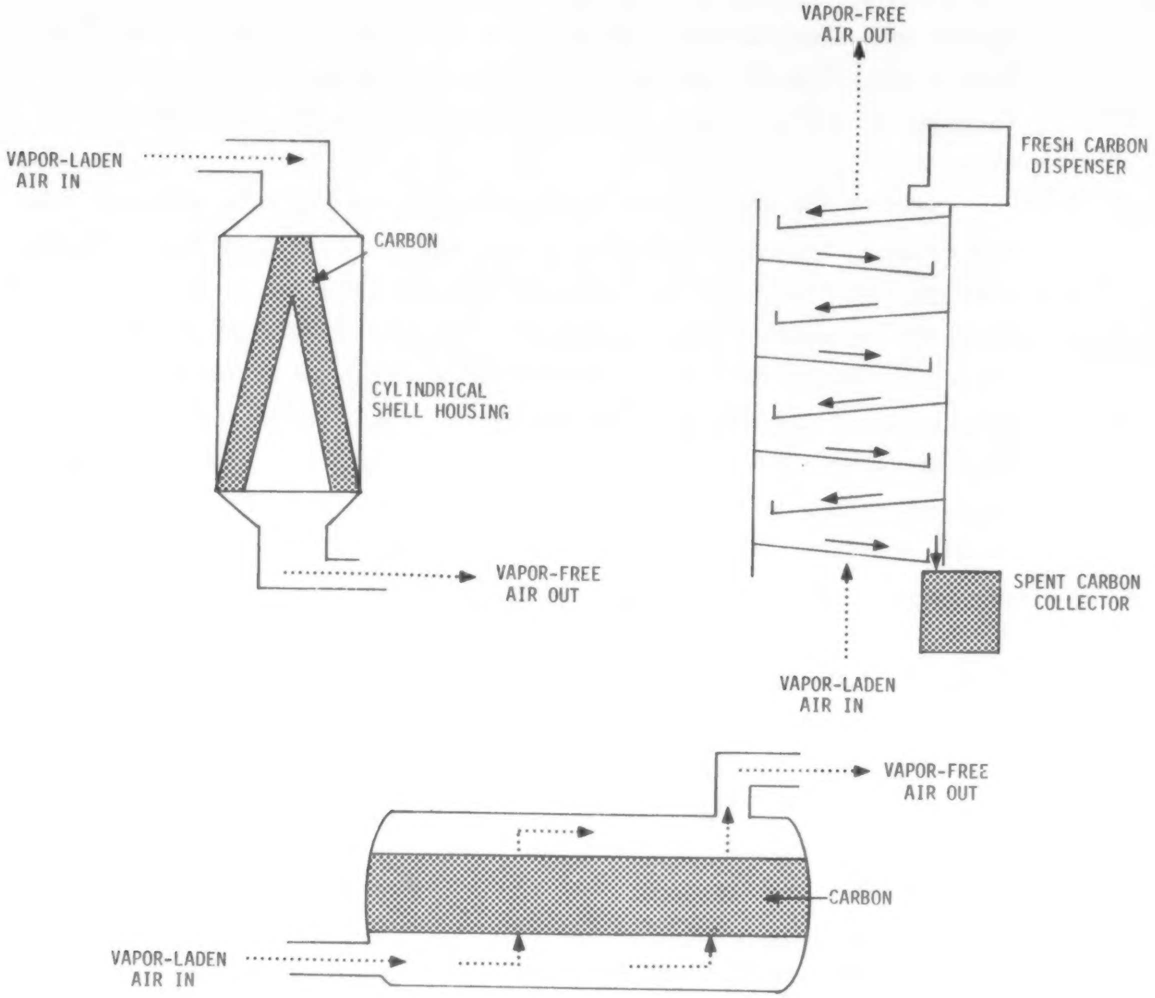

VAPOR-LADEN AIR IN
CARBON
CYLINDRICAL SHELL HOUSING
VAPOR-FREE AIR OUT
VAPOR-FREE AIR OUT
FRESH CARBON DISPENSER
SPENT CARBON COLLECTOR
VAPOR-LADEN AIR IN
VAPOR-FREE AIR OUT
CARBON
VAPOR-LADEN AIR IN

Figure 4-4. Carbon Adsorption Methods

The third producer employing carbon adsorption as a means of solvent recovery from their cellulose acetate production lines uses a common adsorption system which serves both filament and tow product lines. The two solvent recovery processes associated with filament extrusion operations and tow extrusion operations are housed in separate facilities. Two vapor-air ducts and a room-air duct connect the two facilities. The solvent recovery system is common to both operations inasmuch as all absorbers are interconnected via the room air and vapor ducts.

Some of the room air is moved directly via the room air duct from the filament extrusion building to the tow extrusion building. Heated room air is drawn into the filament spinning machines as quench air. Concentrated solvent vapor-laden air from the spinning machines is ducted to adsorption units. The recovery process differs in the production of the two types of fiber, textile filament and tow only in that the vapor-laden air is cooled before adsorption in the filament recovery system by means of a wet (spray) cooler; while in the tow recovery system, the vapor laden air is cooled using dry coil heat exchangers. As with the other adsorber systems mentioned previously, steam is introduced into the bottom of the carbon beds to desorb acetone. Condensers and distillation stills are used to recover 98 percent of the collected acetone for reuse in fiber production.

This same fiber producer also employs carbon adsorption at another filament yarn facility. However, a different solvent recovery strategy is used. This system involves the reuse of plant air from the three basic process areas of the fiber plant. Room air from the dope preparation area (dissolving, mixing, filtering) and room air from the twisting/coning/beaming area, both of which contain low levels of solvent, are vented to the extrusion room at a predetermined flow rate. The extrusion room air is then drawn into the spin cell to supply the quench air for solvent evaporation. Quench air containing a high concentration of solvent is vented together with a fixed amount of extrusion room air (which contains a low level of solvent) to the carbon adsorption system. The solvents recovered at this facility include methylene chloride, acetone, and methanol. Again, steam is used to desorb the solvents. A separate distillation column is used for each solvent fraction. Solvent recovery at this facility is approximately 95 percent.

4.3.1.2 Wet-Spun Spandex Fibers (Reaction Spun Spandex).[20] As identified in Chapter 3 of this document, wet spinning of spandex fibers or reaction spinning is performed by extruding a polyester prepolymer through spinnerets at a constant rate into a solution of (usually) ethylenediamine in toluene. A chemical reaction precipitates the polymer, which is withdrawn from the bath and placed on a moving, heated conveyor belt. The chemical cross-linking reaction continues for the duration of the process. From the heated conveyor the fiber is drawn through an oven, then wound on packages.

Air pollutant emissions from the reaction-spun spandex process line originate at the spin bath, the heated conveyor belt, and from the oven. Essentially, all air that enters the spinning room is drawn into the hooding that surrounds the spin bath and conveyor belt. This stream is ducted to a carbon adsorption system. The first stage of the oven is also vented to the carbon adsorber.

The carbon is regenerated with steam. Condensed steam and solvent is sent to the solvent recovery area. There is some diamine and prepolymer in the aqueous phase of the condensate. After decantation of the toluene, gentle agitation causes the remaining organics to globulate, which makes them easy to separate from the aqueous phase. The toluene is purified in a flash distillation column.

Overall solvent recovery associated with the reaction-spun spandex process is currently not as efficient and economical as in other fiber production processes. Over 99 percent of the organic vapors evolved in the reaction-spun process are captured and sent to solvent recovery. However, a rather complex fouling phenomenom in the carbon bed decreases the solvent recovery efficiency to less than 90 percent rather quickly. Apparently, unreacted prepolymer and diamine cause such severe carbon bed fouling within the adsorption system that the carbon pellets are cemented into a hardened asphalt-like solid. The consequential removing, shipping, and reactivation of the carbon is a large expense to the producer. It appears from an investigation into the carbon fouling problem that there is no short-term solution to the lower solvent recovery efficiency associated with the reaction-spun spandex process.

4.3.2 Gas Adsorption Equipment Performance

Custom packaged carbon adsorption designs feature flow rate accommodations of less than 100 scfm to 80,000 scfm. Review of exhaust flow rate data from the synthetic fibers industry, show that flow rates from uncontrolled emission sources range from 5,000 acfm to 60,000 acfm. On the average, VOC exhaust gas characteristics are reported to range from 100 ppm to 3,000 ppm, falling well within design specifications. As identified in the previous section, carbon adsorption efficiencies range from 92 to 98 percent. Several factors are attributable to this range of collection efficiencies. Recent industry efforts to recover residual acetone have included the treatment of all dryer exhaust gas for solvent recovery. As a result of high moisture content in the gas stream and the presence of finish oils which contaminate the carbon beds, the adsorption efficiencies achieved on treatment of this gas stream are somewhat lower than other carbon adsorption applications.[21,22] Therefore, based on industry operating experience, a recovery efficiency of about 92 percent is normally expected for carbon adsorption systems servicing streams with high moisture content.

It appears that solvent-laden air streams containing two or more VOC's, such as that encountered at the facility that produces cellulose triacetate textile filament yarn, may result in several adverse effects upon the carbon adsorption system. Adsorption of organic compounds having higher molecular weights will tend to displace those having lower molecular weights. Lighter compounds will tend to be separated or partitioned from the heavier and will pass through the bed at a faster rate. This will increase the mass transfer zone, and may require additional carbon bed depth, or shorter operating cycles. Also, carbon retentivity may be reduced in accord with the above, and breakthrough conditions may result for lower-boiling materials. The LEL of the mixture will also vary directly as the LEL of the individual components. Thus, safety considerations might require more or possibly less dilution air with multiple organic feeds. Due to the adverse effects associated with solvent-laden air streams containing two or more VOC's, the carbon adsorption efficiency of any given system will tend to be lower with a multiple organic feed than with a single organic feed.[23] Therefore, the typical efficiency for a system handling a multiple organic feed is expected to be approximately 95 percent.

4.4 CONDENSATION[1,19,24,25]

Recovery of condensible vapors is accomplished by passing vapor-air or vapor-inert gas mixtures over relatively cold surfaces, resulting in direct condensation of the vapors. The principle of condensation of solvent vapors is the operation of the condenser at increased pressure or reduced temperature to change the solvent from its vapor to the liquid phase, simplifying recovery or further processing.

The two types of condensers that can be employed are contact and surface condensers. Contact condensers require that the coolant physically mix with the vapor-laden gas stream, and this method is the more efficient of the two. However, in contact condensation, the condensate is contaminated with the coolant liquid, and further treatment is necessary for condensate recovery. For this reason, the surface-type condensers are usually utilized in cases where the condensate will be recovered for reuse, rather than being incinerated or sent to waste treatment.

Most surface condensers are the shell and tube type. The coolant flows through the tubes, and the vapor condenses on the shell side. The amount of cooling required depends on the inlet vapor concentration and flow rate and the design concentration of the exit gas. Also, the presence of any contaminating substances that might be deposited on the cooled surfaces might inhibit heat transfer and reduce condensation efficiency. Also, the inlet vapor temperature is important, since the entire stream must be cooled to the condensation temperature of the compound being removed from the stream.

4.4.1 Applicability to the Synthetic Fibers Industry[16-21]

Condensers are used throughout the synthetic fibers industry, and are used both independently for solvent recovery or as part of a larger recovery system that may include scrubbers or carbon beds. In those cases where condensers are used independently, the solvent is usually recovered from a closed loop. Spin cell gas (such as heated nitrogen) that contains a high concentration of solvent vapor is ducted to the condenser, where the solvent is recovered economically (due to the high concentration) for immediate reuse or storage. When used alone for vapor control, refrigeration is the usual means of achieving the low temperatures necessary for efficient condensation. Temperatures as low as -120°F are normal. In other cases, condensers may collect the steam and concentrated vapor from carbon beds (during the regeneration cycle), to be followed by distillation or decantation to separate the solvent from the condensed mixture.

4.4.2 Performance Characteristics

The operation efficiencies and costs for condensers depend on the following:

- the concentration and nature of the vapors in the gas stream
- the average temperature difference between the inlet gas and the coolant
- the nature of the coolant or refrigerant
- the presence of noncondensible gases in the inlet gas stream
- the presence of particulates or other contaminants (oils, etc.) in the inlet stream
- utility costs
- recovery credit for reclaimed solvents

In the closed loop operation, where contamination is low and vapor concentration is relatively high, recovery efficiencies are dependent on several variables, but are reported greater than 96 percent for some saturated hydrocarbons. In uses where ambient air is mixed with the vapor and some contamination is present, usual efficiencies of about 90 percent are reported. Advantages and disadvantages of condensation as a control technique are given in Table 4-1.

4.5 DISTILLATION

4.5.1 General Description[26]

Distillation is the separation of compounds usually in the liquid phase by partial vaporization of the mixture and separate recovery of the vapor and residual liquid. The lower the boiling point of a constituent, the greater its proportion in the vapor phase, and the lower its concentration in the residual mixture. The degree of separation of the various compounds introduced depends on the properties of the compounds and the characteristics of the distillation process. Usually,

Table 4-1. ADVANTAGES AND DISADVANTAGES OF EMPLOYING CONDENSATION AS A CONTROL TECHNIQUE[22]

ADVANTAGES

1. Proven technology in other nonrelated industries.
2. Recovered heterogeneous mixtures of organic solvents could be burned in a process boiler.
3. Heat exchangers and low temperature cooling coils can reduce cooling requirements (sometimes up to 75 percent).
4. May perform best as an integral part of other air pollution control equipment.

DISADVANTAGES

1. At a solvent concentration in the 100 to 200 ppm range, refrigeration costs would be very expensive.
2. Large air volumes or particulate matter can reduce condensation efficiencies by as much as 50 percent.
3. Cooling requirements are more demanding for heated exhaust streams, such as from dryers.

distillation refers to the vaporization process in which the vapor evolved is recovered, usually by cooling or condensation.

In batch distillation, the mass of material to be distilled is heated to the boiling point of the material to be recovered in a container, and the vapors pass upward through a column, then to a condenser. This process continues until the distillate concentration in the residual material is reduced to an acceptably low level.

In continuous distillation, a feed stream is partly vaporized while the vapor and liquid portions are continuously withdrawn. Startup of such a unit is the same as in batch distillation, except that no product is removed via the overhead column. When steady state conditions are achieved, the feed is continuously added at some intermediate point in the column. The portion of the column above the feed point is the enrichment section, and the section below the feed point is known as the stripping section. Vapor is continuously withdrawn and condensed. This type distillation is used in conjunction with steam distillation in some applications.

Steam distillation is the vaporization of the feed by blowing live steam through it, and feed of the steam/vapor/volatiles mixture into the separation column. This is especially useful when excessive temperatures should be avoided.

4.5.2 Applicability to the Synthetic Fibers Industry[16-21]

Synthetic fiber producers use distillation extensively in solvent recovery systems. Separation and purification of the solvent used in preparation of the spinning solution is a critical step in fiber manufacture. Manufacture of all but the most exotic and expensive fibers requires recovery and reuse of the solvent for economic reasons.

The solvent fed to distillation is usually mixed with water, or is even a mixture of several solvents, each with a particular function in the overall process. A peculiar phenomenon occurs when several solvents are used and recovered that should be mentioned. While separation and recovery efficiencies of 98 percent and greater are common for distillation of a single solvent from a water/solvent mixture, lower efficiencies are observed in multi-solvent systems. This apparently results from the characteristics of the various azeotropes formed, and more of each solvent is removed from the system than would otherwise occur. (It may also be possible that lower efficiencies result from varying carbon adsorption efficiencies among the constituents, and other phenomena such as preferential breakthrough.)

In dry spinning, the solvent is removed from the vapor stream by use of carbon adsorbers or scrubbers, and the solvent/water mixture is then separated by distillation. In wet spinning, a solution of polymer in solvent is extruded through a spinneret into a spinning bath.[12] The spinning bath contains solvent diluted with water such that it causes the fibers to coagulate at the proper rate. The main feature of wet spinning is the mass transfer of solvent; precipitation or coagulation of the fiber ensues by diffusion of the solvent from the fiber into the bath, and by diffusion of the water into the thread. The resulting spin bath liquid contains large amounts of solvent. This solvent-laden liquid stream is routed to a distillation column where the solvent is recovered for reuse. Liquid streams from the washing and drawing portions of the process are also treated for solvent recovery.

The most important aspect of distillation as it affects the fibers industry is the extreme importance of maximum separation and recovery efficiency. Since thousands of tons of solvent may pass through a distillation column at a typical fiber plant within a single year, even small changes in efficiency would potentially result in the loss or savings of thousands of dollars.

4.6 ENCLOSURES[27]

4.6.1 Applicability to the Synthetic Fibers Industry

A major source of VOC emissions at synthetic fiber plants that utilize an organic solvent to dissolve the polymer is solvent loss which occurs as the fibers proceed from the exit of the spinning cabinet through the various texturizing processes. Residual solvent is volatilized into room and building air at those processing steps not directly served by the solvent recovery collection system. Room and building air is, in most cases, then collected by ventilation systems and either discharged or recirculated in air conditioning systems. In either case, the solvent is maintained at concentrations well below the lower explosive limit and the threshold limit value for the particular solvent. These post-spinning fugitive solvent emissions are eventually directed to the atmosphere. Because enclosures designed to completely envelope process emission sources so as to collect and effectively capture solvent vapors are not typically utilized by the industry as a component of the solvent recovery system, residual solvent volatilized into the room and building air is lost to the process.

One method for reducing post-spinning fugitive emissions would involve an upgrading of ventilation systems serving the fiber processing lines in order to capture a larger portion of the volatilized solvent. Collected gas could then be vented to a control device such as an absorption scrubber or carbon adsorption system. Enclosure of the spinning and post-spinning process line with collected gas sent to a high efficiency control device would likely provide the best system of emission reduction.

Plant visits conducted during this NSPS development have shown that the use of enclosure systems on spinning cell exits and fiber processing lines in the synthetic fibers industry is technologically feasible.[6,10,28,29] Total enclosure systems in use at existing synthetic fiber plants are attached to or comparatively near the source of the pollutant. Figure 4-5 shows a spinning machine with one type of enclosure system. The enclosure functions to reduce the volume of dilution air required to transport solvent-laden air from the workplace. The vapor concentration can be controlled so that the control equipment size and cost are minimized and control efficiency is optimized.

Immediately following the spinning operation, fibers are moved to and through various process operations. The fiber at and near the point of exit from the spinning cell contains substantial residual solvent (as much as 30 percent by weight). This solvent evaporates into the air surrounding the process line. As the solvent evaporates, the vapor-laden air (VLA) can be captured by hooding or enclosures surrounding that particular process operation. The VLA could be subsequently moved via ducts to a control device (scrubber, carbon bed, etc.) or to an atmospheric discharge point.

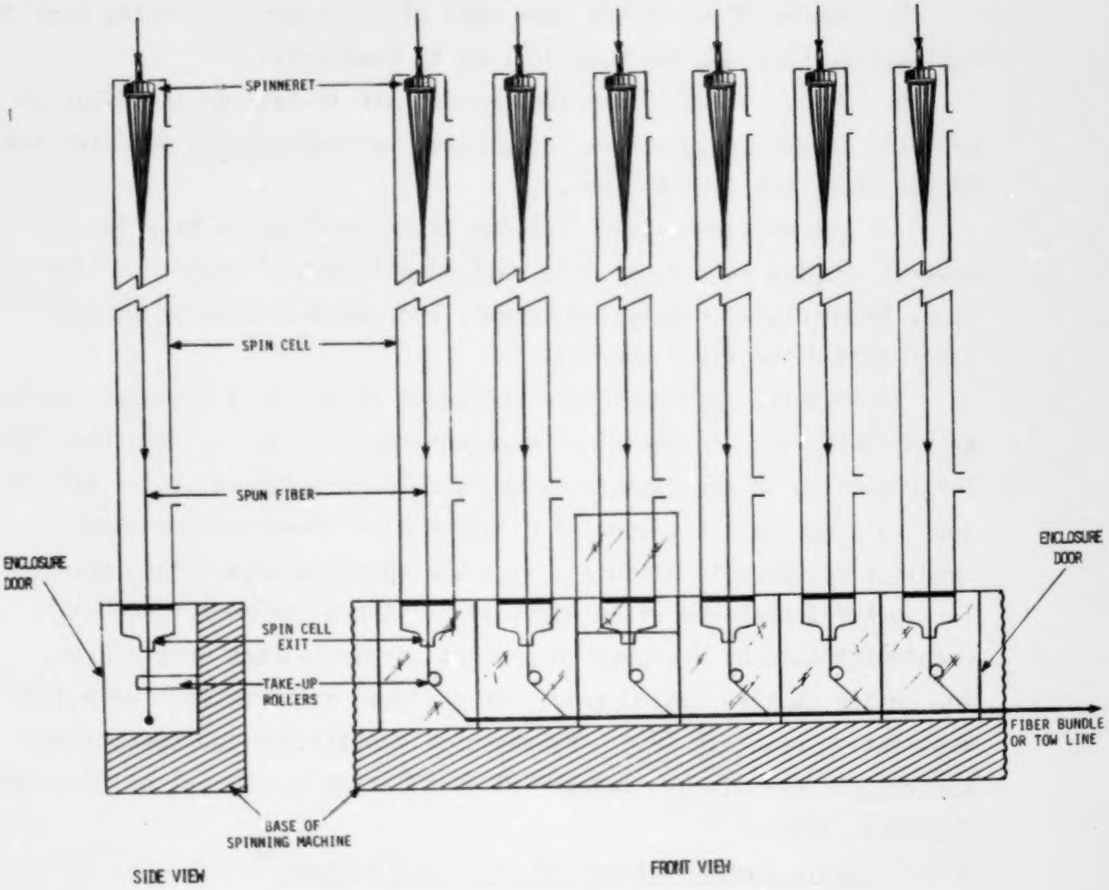

SPINNERET
SPIN CELL
SPUN FIBER
ENCLOSURE DOOR
SPIN CELL EXIT
TAKE-UP ROLLERS
ENCLOSURE DOOR
FIBER BUNDLE OR TOW LINE
BASE OF SPINNING MACHINE
SIDE VIEW
FRONT VIEW

Figure 4-5. Spinning Machine With Enclosure

The amount of solvent which would be ultimately collected by the control device is a function of several parameters:

1. Control device (scrubber, carbon bed) efficiency,
2. Leakage of VLA from ducting,
3. Air in-leakage to ducting,
4. VLA flow rate, temperature, humidity, i.e., physical parameters of the VLA itself,
5. Degree of enclosure (how much of the fiber processing line is enclosed by hooding; how much is open to room air),
6. Design of enclosure (determines air in-leakage and dilution of VLA), length of enclosure (determines residence time) and size and number of worker access doors,
7. Evaporation rate of solvent from the fiber (a function of several complex parameters, the most significant of which are fiber type, temperature, physical movement, and concentration of solvent vapor around the fiber bundle).

Ultimately, each enclosure should be as nearly a "complete enclosure" as possible with minimum sized openings where access is required. Any large opening in the capture system should be equipped with a self-closing door to minimize the amount of dilution air. However, permanent openings designed to allow air flow and openings used intermittently for worker access are often necessary. Covers for worker access openings should be designed to prevent air in-leakage when closed. The entire capture system should be designed in accordance with good ventilation practice (e.g., Handbook of Ventilation for Contaminant Control, McDermott; and Industrial Ventilation - a Manual of Recommended Practice, ACGIH).[21,30]

4.6.2 Safety Considerations of Enclosure Systems[31]

The three requirements for an explosive mixture are fuel (solvent), oxidizer (air), and heat. Since the amount of solvent contained within the fiber as it exits the spin cell is process-dictated, that value is considered a constant (not a variable for purposes of this discussion). The velocity and amount of air into which the solvent evaporates are variable quantities, up to the limits of the fiber to withstand the impinging air flow. As important from a recovery standpoint is the limit on air flow posed by the cost of air/solvent vapor treatment in the recovery device. A compromise is therefore necessary between the risk associated with higher concentrations, and the costs of treating larger air volumes.

The most significant factor in explosion/fire prevention within the recommended enclosures is maintenance of the solvent concentration at desired levels. Estimates show the concentration within the enclosures, that will result from application of the recommended control options, will not approach the LEL for any of the solvents considered. For example, the flow rate of 15,000 cfm and evaporation rate of about 7 kg/hr of acetone will yield about 3,000 ppm or about 15 percent of the LEL under normal conditions. If this concentration is not exceeded, the explosion risk is almost nil. Whether the concentration is allowed to increase to near explosive levels is critical, however. This can be prevented by proper design and use of exhaust fans, dampers, monitoring equipment, etc. An appropriate combination of automatic and manually operated fail safe measures, plus effective supervision of the equipment should prevent hazardous situations from occurring.

Solvent-laden air streams which are transported to control equipment are normally maintained at concentrations at or below 25 percent of the lower explosion limit (LEL) of the solvent. Although 25 percent of the LEL is often regarded as the maximum allowable solvent concentration, insurance and safety requirements will sometimes permit even higher solvent concentrations. The Handbook of Industrial Loss Prevention notes that flammable vapor concentrations of up to 50 percent of the LEL may be tolerated if approved continuous vapor concentration indicator controllers are used.

The monitors should be set to first adjust the inflow of dilution air at relatively low concentrations, then activate alarms at higher concentrations, and finally shut down the spinning machines when unacceptable levels are reached. Several monitors should be utilized for redundancy and added safety margin. At some concentration level, perhaps near the alarm level, operator access doors should be opened, either automatically or manually when the alarm level is reached. In addition, power for operation of the exhaust fans should be received from at least two independent sources such as electrical power and steam turbines. Nonelectrical means of purging could be utilized as well, such as steam aspirators or air pressure tanks which could evacuate or force air/solvent vapors out of the enclosed areas.

Another preventive measure could be the installation of distribution pipes and nozzles for blanketing the area with either nitrogen or carbon dioxide when explosive mixtures are reached. This would both blanket the area and dilute the potentially explosive vapors. This system would be effective for both prevention of explosive conditions and extinguishing of fires once started. There should be some means of controlling the inert gas or carbon dioxide so that employees are not overcome.

The ignition of flammable vapors may occur as a result of spark discharge of static electricity. Changes may be generated by friction between surfaces such as fibers and guides, or even by movement of the fiber through the spin cell atmosphere. The rotating metal take-up wheels moving against small quantities of waste fiber could also generate a static charge or heat from mechanical friction. Protection against these hazards should begin with determination of the locations where static charges are likely generated, and installation or use of means for gradual dissipation of these charges without spark discharges. All metal parts, for example, should be mutually grounded. (Note that water and steam pipes are unreliable for use as conductors or grounds.)

It has been shown that explosions in chemical process plants are usually the result of nonroutine leakage of flammable materials. Thus, prevention should include strict housekeeping and prompt repair of leaking lines, particularly lines containing pure solvents or solvent/water mixtures, or spinning dope. A spill of any of these would quickly result in flammable air/vapor mixtures above or near the spill.

There are other relevant factors bearing on explosive characteristics. Decreases in ambient temperature and pressure reduce the range of flammable mixtures that will ignite. There is also evidence that increases in flow velocity will decrease the flammable limits. If the diluent air is cooled, the explosive range is narrowed

(LEL increased and UEL decreased). The conclusion is therefore that if the ventilation inlet air to the enclosures is cooled, moved rapidly, and/or drawn out under negative pressure, the possibility of ignition will be reduced. In addition, the reduction in temperature would have the added effect of causing slower evaporation of acetone from the moving fibers.

Still another important air conditioning parameter from a fiber characteristic as well as safety standpoint is humidity. It is important to keep a minimum of 55 to 60 percent relative humidity, both to reduce static discharge and to reduce breakage due to brittle fibers.

As a minimum, the design of the process and recovery systems, particularly the enclosure systems, should consider all the foregoing preventive measures, and industry experience in reducing the risks of explosive conditions as far as economically possible. The equipment and procedures must be able to function not only in normal service, but especially during emergency or nonroutine periods. Explosive conditions may be avoided with proper and adequate selection of monitoring and control instrumentation and adequate supervision of the process and monitoring equipment.

The use of capture/enclosure devices similar to those described above, for use on synthetic fiber spinning and processing lines, have also been recommended in other studies regarding specific segments of the fibers industry. These studies have received considerable review by the industry. They include:

- Economic Impact Assessment for Acrylonitrile by Enviro Control, Inc., Contract No. J-9-F6-0229, February 21, 1978, for Occupational Safety and Health Administration
- U.S. Department of Labor Emission, Process, and Control Technology Study of the ABS/SAN, Acrylic Fibers, and NBR Industries, by Pullman Kellogg, Contract No. 68-02-2619, April 20, 1979, for ESED, OAQPS, U.S. Environmental Protection Agency.

4.7 INCINERATION[32-35]

An alternative means of reducing VOC emissions, other than by increasing the solvent recovery efficiency, is incineration of the solvent vapor. Incineration control devices operate on the principle of combustion, through oxidation of gas stream constituents into (primarily) products of carbon dioxide and water. Process exhaust streams which flow into the incinerator will likely be below 25 percent of the LEL. Hence, to effectively accomplish combustion, fuel must be added to the diluted vapor before incineration occurs. Devices which add fuel to diluted vapor streams and incinerate the combined stream are referred to as afterburners. Other energy needs within the plant can often be supplemented by the heat produced during combustion. Two types of afterburners may be used to reduce process emissions, direct flame (thermal) and catalytic oxidizers.

Thermal incinerators consist of a mixing chamber designed to provide contact between the vapor-laden gas stream and the burning flame, followed by a combustion chamber. The efficiency of a thermal afterburner is affected by the air-fuel-vapor concentration ratios, residence time required for complete combustion, and sufficient temperature to ensure complete oxidation of the combustibles. Burner type and placement also determine thermal afterburner efficiency. Multi-jet and mixing-plate burner types prove most effective in maximizing flame and vapor-laden air content. Incomplete combustion of gas constituents may permit carbon monoxide, aldehydes, or other reactive compounds to be exhausted from the unit. Natural gas, LPG, and distillate and residual fuel oils are used to fuel afterburners and create the potential for reactive halogens, sulfur oxides, and organic acids to be exhausted into the atmosphere if low combustion efficiencies are encountered. Figure 4-6 shows the design features of a direct flame afterburner.[36]

The design of catalytic afterburners is similar to direct flame (thermal) units except that combustion is initiated through use of a catalyst. A catalyst is a substance that changes the rate of a chemical reaction without altering the composition of the catalytic material. Catalytic afterburners employ a solid active surface on which the combustion process occurs. Preheated process gases are directed through a heated catalytic bed, usually a honeycomb network of platinum or palladium, which promotes oxidation. Thin layers of the catalytic metal are deposited on an inert substrate of variable shape. The

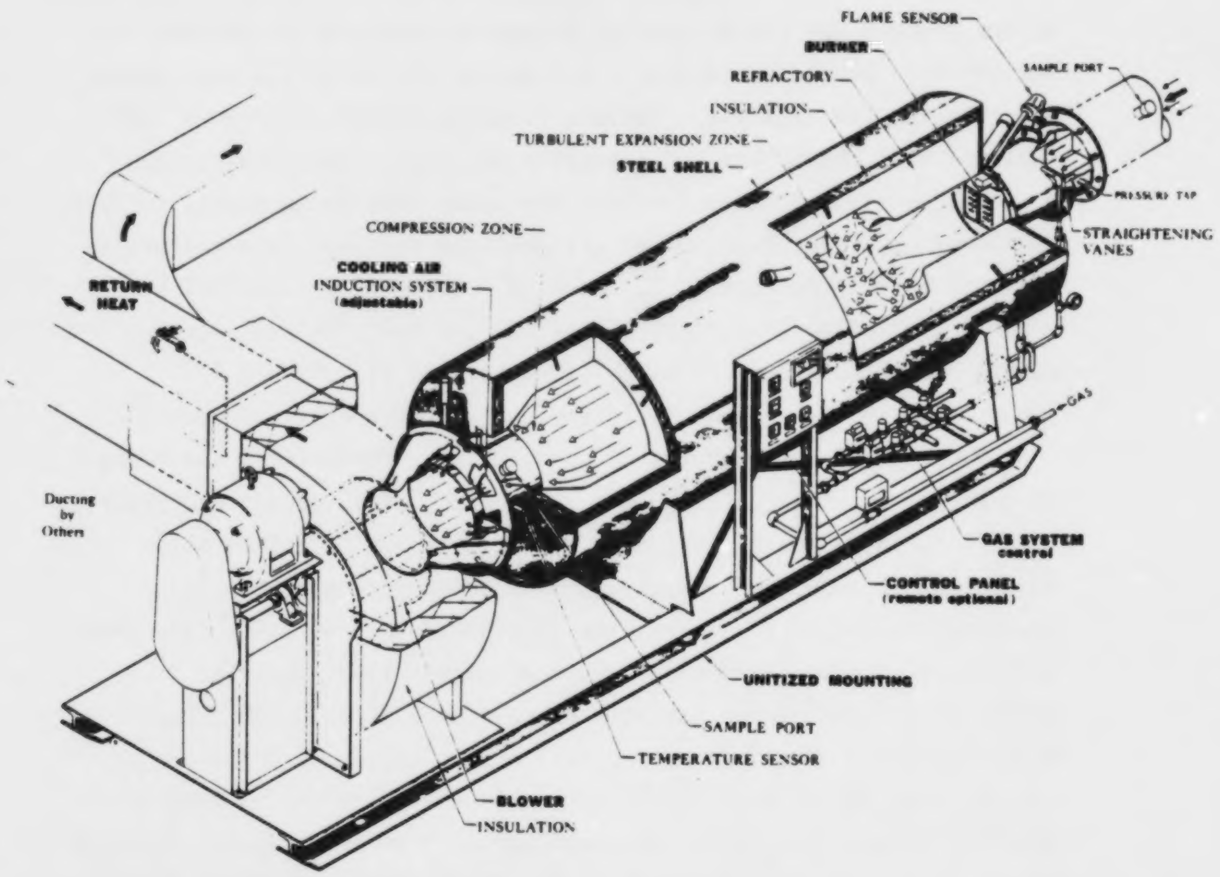

FLAME SENSOR
BURNER
REFRACTORY
INSULATION
TURBULENT EXPANSION ZONE
STEEL SHELL
SAMPLE PORT
PRESSURE TAP
STRAIGHTENING VANES
COMPRESSION ZONE
COOLING AIR INDUCTION SYSTEM (adjustable)
RETURN HEAT
Ducting by Others
GAS
GAS SYSTEM control
CONTROL PANEL (remote optional)
UNITIZED MOUNTING
SAMPLE PORT
TEMPERATURE SENSOR
BLOWER
INSULATION

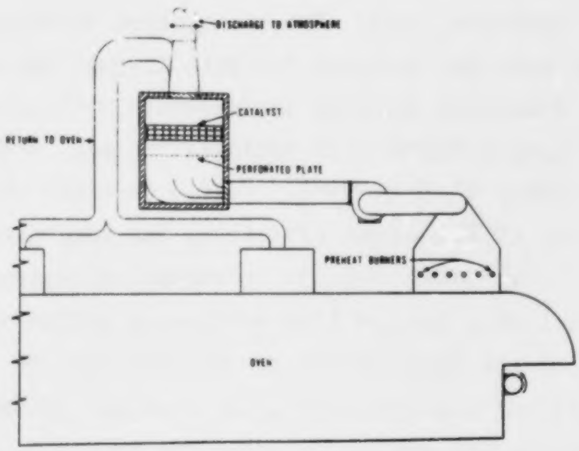
Figure 4-6. Sectional View of Direct-Flame Afterburner[3]

catalytic material provides a large surface area containing active sites upon which the gas molecules can react. Catalytic afterburners thus require less fuel and operate at lower temperatures than direct flame types.

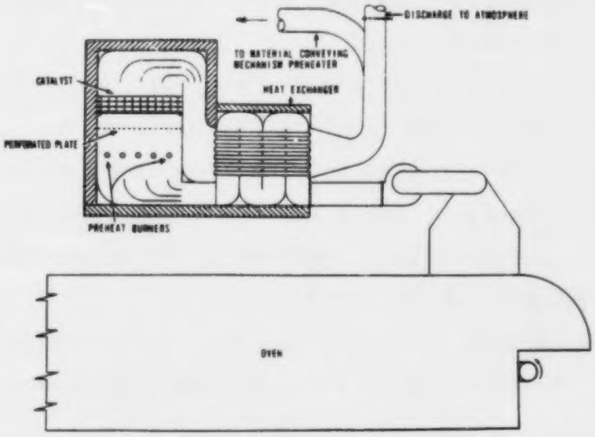
Maintenance for catalytic systems is frequent. Certain constituents of the process gas stream such as polymeric compounds or particulates may not burn properly, causing a buildup on the substrate and thereby deactivating the catalyst. Various cleaning methods to remove such coatings will reactivate the catalytic material. The catalyst may also be deactivated through direct reactions with phosphorous, sulfur, and heavy metals present in the effluent gas stream. In an effort to minimize operational problems, inlet gas stream concentrations are usually limited to 25 percent of the LEL and ignition temperatures maintained between 540° to 650°C (1000 to 1200°F). Figure 4-7 illustrates the use of catalytic incinerators for heat recovery.[37]

VOC control efficiencies of direct flame afterburners can reach 98 percent; catalytic afterburner VOC control efficiencies are reported to be between 81 and 96 percent.[38] Effectiveness of incineration technology in reducing VOC emissions is dependent upon: the vapor ignition temperature; chamber size and turbulence; effluent flow rate; as well as afterburner design. Typical design flow rates for direct-flame afterburner packages range from 250 to 50,000 scfm/unit, while catalytic afterburners are designed to accommodate flow rates ranging from 400 scfm to 40,000 scfm. Custom-built units, capable of handling larger flow rates, are available. However, industry-supplied data indicate that conventional packaged designs are suitable for treating typical process exhaust streams.

Incineration is an emission control technique that could be used to reduce VOC emissions from the synthetic fibers industry. Presently, however, synthetic fiber facilities do not utilize the option of incineration to control VOC's. Primarily this is because existing control equipment was installed to recover increasingly expensive solvent for the purpose of cost optimization. Incineration is a destructive method of emission control directly opposing solvent reclamation efforts. The results of a study which examined the economic


DISCHARGE TO ATMOSPHERE
CATALYST
RETURN TO OVEN
PERFORATED PLATE
PREHEAT BURNERS
OVEN

Catalytic incinerator utilizing direct heat recovery


DISCHARGE TO ATMOSPHERE
TO MATERIAL CONVEYING MECHANISM PREHEATER
CATALYST
HEAT EXCHANGER
PERFORATED PLATE
PREHEAT BURNERS
OVEN

Catalytic incinerator utilizing indirect heat recovery

Figure 4-7. Catalytic Incinerators Utilizing Heat Recovery

feasibility of incineration as a VOC control technique in the synthetic fibers industry appear to substantiate this claim.[32,39] In the report, six individual incineration systems were analyzed to determine capital and annual operating cost. The six systems included three separate cases; each case was analyzed for both thermal and catalytic incinerators. The Case 1 situation involved incineration with no recuperative heat recovery. Case 2 represented incineration with primary heat recovery at an efficiency of 35 percent. Case 3 involved the use of primary heat recovery at 35 percent efficiency and secondary recovery at 55 percent efficiency. The six incineration systems were then compared with the cost of a low and high efficiency carbon adsorption system. The result of the study indicated that the cost of incineration is significant; and when compared with a solvent recovery system, such as a carbon adsorption system, incineration does not appear to be an economically viable control option for the synthetic fibers industry. Other disadvantages to incineration include:

- Fuel is continuously burned regardless of whether the exhaust stream is intermittent or has fluctuating concentrations;
- Incompletely combusted VOC's including the auxiliary fuel may be potent smog precursors;
- Secondary air pollutants (NO_x, SO_x, CO) present in afterburner exhaust, may contribute to air pollution problems;
- Low sulfur content fuels are recommended for operation of incinerators; however, these fuels are expensive and not always available.
- The energy impacts required to raise the contaminant air stream to 1,500°F may be significant.
- Gas streams with very low VOC concentration may require significantly more fuel to achieve temperatures around 1,500°F.

4.8 EMISSION AND PROCESS TESTING

Volatile organic compound (VOC) emissions were the principal type of air pollutant encountered during the testing of emissions from fiber producing plants. These emissions result primarily from organic solvents used during fiber producing operations. Processes tested under the emission measurement program utilized either dimethylformamide (DMF) or dimethylacetamide (DMAc) as the spinning solvent.

Baseline emission values have been determined by combining and reducing data obtained from a variety of sources. By integrating information acquired through literature searches, EPA 114 responses, plant surveys, and emission test data, mass balance calculations have been performed. For the purpose of determining a plant's compliance, there are two methods theoretically available for calculating emissions: direct measurement of emissions and indirect determination by mass balance.

Two sites were chosen for field testing for direct measurement of VOC emissions. One plant operated a dry spinning process, whereas the other plant operated a wet spinning process. Vents and stacks were identified and prioritized according to the relative amount of VOC's emitted to the atmosphere. In order to determine solvent vapor concentrations and distribution within enclosures such as those described in Section 4.6, testing was performed at one plant that already utilizes this type capture technique. Emission test reports have been issued and describe in full the testing procedures and methods employed (see Appendices C and D).

In addition to direct measurement of VOC's via field testing, EPA also obtained solvent use information from six different fiber plants covering the previous 2 years (1979-1981). The solvent use information can be indirectly used to determine VOC emission rates, since makeup flow rates are exactly equivalent to the total of nongaseous losses (as determined by prior actual measurements) and air emissions. This solvent use data is summarized in Appendix C. The amount of makeup solvent is measured by totalizing flow meters, an inexpensive, simple, and continuous method of indirectly determining VOC emissions.

4.9 SUMMARY

A description of the solvent capture and recovery techniques presently employed in the synthetic fibers industry was presented in this chapter, and five techniques employed in the synthetic fibers industry to recover solvent from wet, dry, and reaction spinning processes were outlined. They include gas absorption, gas adsorption, condensing, distillation, and enclosure and capture systems.

Table 4-2 summarizes the more common recovery process technologies currently in use in the industry, along with the fiber types utilizing these techniques.

Table 4-2. SUMMARY OF CONTROL TECHNIQUES

	Dry-Spun Acetate Filter Tow	Dry-Spun Acetate Filament	Dry-Spun Modacrylic	Wet-Spun Modacrylic	Wet-Spun Acrylic	Dry-Spun Acrylic	Dry-Spun Spandex	Wet-Spun Spandex
Number Plants	2 Plants	3 Plants	2 Plants	1 Plant	1 Plant	1 Plant	1 Plant	1 Plant
Adsorbers	● ●	● ●						●
Absorbers	●	●	● ●			●		
Condensers	● ●	● ● ●	● ●	●	●	●	●	●
Distillation	● ●	● ● ●	● ●	●	●	●	●	●
Enclosures (not including simple hoods etc).			●	●	●	●		
Incineration								

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5.0 MODIFICATION AND RECONSTRUCTION

5.1 BACKGROUND

Emission limitation standards promulgated under Section 111(b) of the Clean Air Act apply to all facilities within the regulated source category that are constructed, modified, or reconstructed after the date of proposal of the standards. Uncertainties may arise as to the determination of whether any existing facility has been "modified" or "reconstructed." These issues are addressed in Sections 60.14 and 60.15, respectively, of Title 40 of the Code of Federal Regulations, which defines conditions under which an "existing facility" may become subject to standards of performance.[1,2] An "existing facility," defined in 40 CFR 60.2(aa), is an apparatus of the type for which a standard of performance is promulgated and the construction or modification of which was commenced prior to the date of proposal of that standard.

The following discussion examines the applicability of the modification/reconstruction provisions to any facilities for the manufacture or processing of synthetic fibers in existing fiber manufacturing plants, and details conditions under which existing facilities could become subject to standards of performance for new stationary sources. The enforcement division of the appropriate EPA regional office should be contacted regarding any questions on modification or reconstruction applicability.

5.2 40 CFR PART 60 PROVISIONS FOR MODIFICATION AND RECONSTRUCTION

5.2.1 §60.14 Modification

§60.14 states:

". . ., any physical or operational change to an existing facility which results in an increase in the emission rate to the atmosphere of any pollutant to which a standard applies shall be considered a modification within the meaning of Section 111 of the Act. Upon modification, an existing facility shall become an affected facility for each pollutant to which a standard applies and for which there is an increase in the emission rate to the atmosphere."[1]

Paragraph (b) clarifies what constitutes an increase in emissions in kilograms per hour and the procedures for determining the increase including the use of emission factors, material balances, continuous monitoring system and manual emission tests. Paragraph (c) affirms that the addition of a facility subject to performance standards to a stationary source does not make any other facility within that source subject to standards of performance. Paragraph (f) simply provides for superseding any conflicting provisions.

Paragraph (e) lists certain physical or operational changes which by themselves are not considered modifications. These changes include:

(1) Facility maintenance, repair, and replacement which are determined by the Administrator to be routine.

(2) An increase in the production rate not requiring a capital expenditure as defined in §60.2(bb).

(3) An increase in the hours of operation.

(4) Use of an alternative fuel or raw material if prior to the standard, the existing facility was designed to accommodate that alternate fuel or raw material. (Conversion to coal, as specified in §111(a)(8) of the Clean Air Act, is also exempted.)

(5) The addition or use of any system or device whose primary function is the reduction of air pollutants, except when an emission control system is removed or replaced by a system considered to be less efficient.

(6) The relocation or change in ownership of an existing facility.

An increase in the production rate of an existing facility is designated as a modification only if there is an increase in the emission rate and the total cost necessary to accomplish the change constitutes a "capital expenditure." Capital expenditure is the product of the facility's original cost, as defined by Section 1012 of the Internal Revenue Code, and the appropriate "annual asset guideline repair allowance percentage" (AAGRAP). The 1978 edition of Internal Revenue Service Publication 534[3] sets the AAGRAP for the synthetic fiber manufacturing industry at 16 percent. Therefore, if the total cost of increasing the production rate of an existing synthetic fiber manufacturing facility exceeds 16 percent of the facility's original cost, and if this change causes increased emissions, the facility would be considered to have been modified.

5.2.2 §60.15 Reconstruction

§60.15 states:

> "An existing facility, upon reconstruction, becomes an affected facility, irrespective of any change in emission rate. 'Reconstruction' means the replacement of components of an existing facility to such an extent that: (1) the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility, and (2) it is technologically and economically feasible to meet the applicable standards set forth in this part."[2]

Reconstruction, as defined in 40 CFR 60.15, occurs when the fixed capital cost of replacement components of an existing facility exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility, and it is technically and economically feasible to meet the applicable standards. After receiving notice from the owner or operator as required under 40 CFR 60.15(d), the Administrator will determine whether the proposed replacement constitutes a reconstruction. In accordance with 40 CFR 60.15(f), the Administrator's decision is based upon the following: (1) the fixed capital cost of the replacement components, (2) the estimated life of the facility, (3) the extent to which the components being replaced cause or contribute to the emissions from the facility, and (4) any economic or technical limitations on compliance that are inherent in the proposed replacements. Investigation of the synthetic fibers manufacturing industry does not reveal any history of changes that would render a line subject to the reconstruction provision. Repair or rebuilding of an existing facility where costs would exceed 50 percent of the cost of replacing the facility would be unusual.

5.3 APPLICABILITY TO SYNTHETIC FIBER MANUFACTURING PLANTS

5.3.1 General

Investigation of the processes used by manufacturers of synthetic fibers does not reveal any particular practice which can be readily classified as a modification or reconstruction. A number of potential actions have been identified which, under certain circumstances, may indeed be so classified. The following sections are concerned with alterations common to those process facilities which would be affected by the application of the modification and reconstruction provisions. In Sections 5.3.2 and 5.3.3, other practices specific to each process facility are discussed.

5.3.2 Modifications

Investigation of the processes used by manufacturers of synthetic fibers does not reveal any particular practice, other than the direct addition of production equipment, which can be readily classified as a modification. There are, however, a number of routine alterations common to synthetic fiber production facilities which would not likely be affected by the application of the modification provision, even though many of these changes can affect solvent emissions, some positively and some negatively. Some examples are: changes in fiber properties such as denier; variation in drawing, washing, and stretching operations; routine alterations in co-polymer to co-polymer and polymer to solvent ratios; changes in additives and finishing oils; and normal variation in spin and wash bath temperatures. Any increase in VOC emissions effected by these routine changes in the manufacturing process would not be considered a modification since they are considered to be within the normal operation of a facility as designed.

5.3.2.1 Production Rate Increases. An increase in production rate at an existing facility is not in and of itself a modification under §60.14 if the increase can be accomplished without incurring a capital expenditure at the affected facility.* If a capital expenditure less than the product of the most recent annual asset guideline repair allowance published by the Internal Revenue Service (Publication 534) and the facility's basis is made to increase capacity at an existing facility and also results in an increase in emissions of a regulated pollutant to the atmosphere, a modification is not considered to have occurred.[4] Any fiber manufacturing plant is designed for a maximum production capacity, which is directly related to the maximum capacity of the spinning cells and the number of these spinning cells or cabinets. Process stages other than spinning (e.g., dissolving/blending or drying) may have capacities which exceed the total plant capacity for finished fiber. Thus, an increase in the production capacity of a plant is possible without a capital expenditure if only those facilities which limit fiber production (de-bottlenecking) are modified. For example, an increase in the plant production capacity might be accomplished by changing from batch processing to continuous processing or the addition of spinning cabinets (or spinnerets). If the additional line(s) were part of a facility for which NSPS are established, it would be subject to NSPS if the addition caused an increase in VOC emissions and if the capital expenditure criteria were met.

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*Capital expenditure is defined as "an expenditure for a physical or operational change to an existing facility which exceeds the product of the applicable annual asset guideline repair allowance percentage specified in the latest edition of Internal Revenue Service Publication 534, and the existing facility's basis, as defined by Section 1012 of the Internal Revenue Code." (40 CFR 60, Sect. 60.2[bb]).

5.3.2.2 Change in Raw Materials. A modification in the polymer and/or co-polymer introduced into the process will likely have a minor effect on the solvent (VOC) emissions. The change in emissions would probably not be measurable, and the overall effect would be negligible. Changes in solvent use practices may result in a rise of the VOC emission rate from fiber manufacturing facilities. One possible change would be an increase in the volatility of the solvent caused by temperature increases. This would result in an increase in the quantity of VOC emitted per unit of product. Another change would be the use of solvent with a lower boiling point, although this change of solvent within a plant is not common in the industry.

Another possible change would be to increase the ratio of solvent used per unit of product. This change might be necessitated for desired product characteristic changes. This would create an additional load on the solvent recovery system while maintaining constant product output. Additionally, increasing solvent used per unit of fiber produced would increase costs of solvent recovery and cost per unit of fiber.

A further change which would affect VOC emissions would be a change in water (or other solvent) content of the primary solvent, thus altering the boiling point of the mixture. This is more likely to actually occur within the industry, although the net change in VOC emission would be very small.

These changes would not likely be considered to be modifications and would not cause the facility to be subject to the standard(s), because the changes primarily involve a switch in raw material which the facility was designed to accommodate.

5.3.2.3 Alternative Fuel. The use of an alternative fuel would not be considered a modification if the existing facility were designed to accommodate the alternative.

5.3.2.4 Addition of a System to Control Air Pollutants. The addition or use of any system or device whose primary function is to reduce air pollutants, except the replacement of such a system or device by a less efficient one, is not by itself considered a modification under §60.14. For example, the replacement of a relatively inefficient scrubber with a more efficient scrubber in an existing installation, for the purpose of improving solvent recovery (solvent that would otherwise be emitted to the atmosphere) would not be considered a modification under §60.14(e)(5).

5.3.2.5 Maintenance, Repair, and Replacement. Maintenance, repair, and component replacement which are considered routine for a source category are not considered modifications under §60.14(e)(1). An increase in emissions is not expected to occur as a result of normal maintenance or replacement of fiber production components.

Routine maintenance would involve periodic cleaning, replacement of parts, and lubrication of moving parts. Routine maintenance should not have any noticeable effect on emissions, since VOC is introduced to the system only when the process is in operation.

Several components can be expected to require replacement as a matter of routine due to the unit being in continuous service for long periods of time. These components may include spinneret heads, fiber guides, scrubber nozzles, and drive gears. Replacement with equivalent components should not affect emissions and would be considered exempt under §60.14(e)(1).

5.3.2.6 Equipment Relocation and Change of Ownership. Relocation of equipment would not constitute a modification.

5.3.2.7 Removal or Disabling of a Control Device. The intentional removal or disabling of any emission control component of an existing installation which would cause an increase of emissions would be a modification. An existing facility that is modified becomes an affected facility subject to the NSPS.

5.3.3. Reconstruction

The term reconstruction means the replacement of components to an extent that the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable, entirely new facility (40 CFR 60.15). Repair or rebuilding of an existing facility at a cost exceeding 50 percent of the cost of an entirely new facility is unusual. There are no general conditions which can be classified as a reconstruction. As stated previously, production rate increases are usually met by adding new lines to existing facilities rather than rebuilding lines in existing facilities. The one common exception is conversion of cellulose acetate textile yarn capacity to filter tow capacity. Determination of whether any repair or rebuilding activities constitute reconstruction must be made by the Administrator on a case-by-case basis.

If a previously closed plant were to reopen, it would not be subject to NSPS unless one or more of the facilities for which standards had been promulgated were altered sufficiently to meet reconstruction criteria. Then, only those facilities which had been altered and for which standards exist would be subject to NSPS.

Determination of reconstruction is based on the capital cost of all new construction and other technical and economic considerations. The Administrator will consider if it is technically and economically feasible to meet the applicable standards in making any reconstruction determination. For synthetic fiber production facilities, retrofitting solvent recovery equipment to existing plants can pose certain problems.

The amount of physical space necessary to install ventilation and ductwork to capture solvent from process lines is a definite constraining factor. Equipment and personnel must be able to move down process line aisles without being hindered; therefore, installation of enclosures at some existing facilities may not be possible without a complete reconstruction of the entire spinning area.

Also, the cost of installing a control system in an existing plant is greater than the cost of the system for a new facility with the same exhaust gas parameters because of special design considerations. In retrofitting systems, additional costs may be encountered because of such items as demolition requirements, crowded construction working conditions, scheduling construction activities with production activities, and longer inter-connecting piping. These constraints must be taken into account when costing the retrofitting of recovery equipment at synthetic fiber plants. Availability of space, additional ducting, and additional engineering must also be considered.

Configuration of equipment in the existing plant governs the location of the control system. Depending on process or stack location, long ducting runs from ground level to the control device, stack, and reprocessing equipment may be required. Costs may increase considerably if the control equipment must be placed on the roof and requires steel structural support. It is estimated that rooftop installation can double the installation costs.

5.3.4 Cellulose Acetate Filament Production Change to Filter Tow Production

An alteration in cellulose acetate production which would possibly qualify as modification or reconstruction is the change from cellulose acetate filament production to cellulose acetate filter tow production. The changes necessary to alter a given filament process line to permit filter tow production would be the removal of bobbin winding equipment and the addition of one or more fiber crimpers and dryers. Also, a finishing step would be added (prior to the crimping step) to provide desired fiber characteristics.

The spinning step would be essentially unchanged, and of the total VOC released, most of the volatilized VOC is generated at this step. Therefore, the changes in the [illegible] spinning processing steps will affect only the residual solvent content of the fiber after the spinning step. Whereas [illegible] was released relatively slowly into the room air from the bobbins containing filament yarn, the [illegible] the process. The addition of a dryer should cause a major portion of the solvent to be released in the heated drying area, which would be more easily collected and controlled. The total solvent ultimately released, however, would be essentially the same in both cases; only the rate of release from a given mass of fiber would be changed, if the dryer were uncontrolled.

step. Therefore, the changes in the post spinning processing steps will affect only the residual solvent content of the fiber after the spinning step. Whereas VOC was released relatively slowly into the room air from the bobbins, containing filament yarn, the filter tow process line addition of a dryer should cause a major portion of the solvent to be released in the heated drying area, which would be more easily collected and controlled. The total solvent ultimately released, however, would be essentially the same in both cases; only the rate of release from a given mass of fiber would be changed, if the dryer were uncontrolled.

5.4 REFERENCES

1. U.S. Environmental Protection Agency. Code of Federal Regulations. Title 40, Protection of Environment, Section 60.2(h), Definitions. Washington, D.C. Office of the Federal Register. Revised as of July 1, 1977. p. 6.

2. U.S. Environmental Protection Agency. Code of Federal Regulations. Title 40, Protection of Environment, Section 60.15, Reconstruction. Washington, D.C. Office of the Federal Register. July 1, 1977. p. 18.

3. Tax Information on Depreciation. U.S. Department of the Treasury. Internal Revenue Service. Washington, D.C. Publication 534. 1978. p. 29.

4. Standards of Performance for New Stationary Sources. Subpart A, 40 CFR 60.15 (44 FR 55173).

6.0 MODEL PLANTS AND REGULATORY ALTERNATIVES

Model plants are parametric descriptions of the types of plants that, in EPA's judgment, will be constructed, modified, or reconstructed. The model plant parameters form the basis for estimating the environmental, economic, and energy impacts associated with the application of the regulatory alternatives to the model plants. Regulatory alternatives are ways in which EPA could regulate emissions from solvent-spun synthetic and semisynthetic fiber manufacturing plants. This chapter will define the model plants and identify the regulatory alternatives as applied to synthetic fiber manufacturing plants.

6.1 MODEL PLANTS[1-6]

The model plants chosen to represent the portion of the synthetic fibers industry under consideration for new source performance standard (NSPS) development are described in this chapter. This study concentrates on the production processes which involve the spinning (extrusion) of the fiber from a solution of polymer or prepolymer and organic solvent(s).

All fiber spinning processes share certain fundamental similarities. Basically, the object is to extrude a liquid or semi-solid polymer in a desired cross section and then solidify it before mechanically taking it up with a collection device. In most processes the solid fiber is subjected to further mechanical processing to enhance its properties; in others, the fiber is taken up essentially as a finished product. Those broadly identifiable process stages which are common to all solvent-spun synthetic fiber processes include: (1) preparation of the spinning solution. In this stage, polymer is dissolved in an organic solvent; the solution is blended with additives and filtered to complete the preparation of the dope for spinning. (2) Spinning of the fiber, that is, the actual formation of the fiber filaments. Polymer solution (or dope) is forced or extruded through a device called a spinneret to create the fiber. (3) Processing of the formed fibers. This might include lubrication, washing, drying, heat setting, finishing, or crimping. (4) Solvent recovery. Because of the large amounts of solvent used (a pound of polymer is typically dissolved in 2 to 3 pounds of solvent), the economics of the industry require that almost all of the solvent used in dissolving be recovered for reuse. Typically, solvent is recovered most efficiently and economically at the spinning step from the spin-cells or spin baths into which polymer solutions are extruded. About 94 to 97 percent of the solvent used is recycled directly from the spinning step alone. Thus, a primary solvent recovery system is an integral part of all solvent spinning processes. Figure 6-1 presents a generalized process flow diagram illustrating these common production stages.

Beyond the similarities, there are many differences among processes. Besides having a stable commodity fiber-producing portion, the industry is also comprised of a relatively dynamic specialty fiber-producing portion, into which new fiber types and production methods are frequently being introduced. Still other solvent-spun types are being produced at pilot scale levels, and may or may not expand to full production (solvent-spun rayon, for example). Consequently, production parameters, such as fiber spinning rates, processing sequences, and polymer/solvent/fiber processing ratios that vary from one fiber producer to another and sometimes within each plant lead to a wide variety of fiber types and production methods for which model plants could be developed.

Thus no single model plant could adequately characterize the organic solvent-spun synthetic fibers industry, since each synthetic fiber manufacturing process is unique. It would be nearly impossible to develop a model plant and associated economic analysis for each conceivable fiber type. Therefore, several model plants were developed such that any organic solvent-spun fiber process (currently existing or unknown) could be technically represented by one of them.

This chapter presents five model plants and two basic fiber types for technical analysis. The five model plants were developed to represent the differences in spinning operations due to resin type, the spinning processes, and the fiber processing stages subsequent to the spinning step. Selection of specific model plant operating parameters

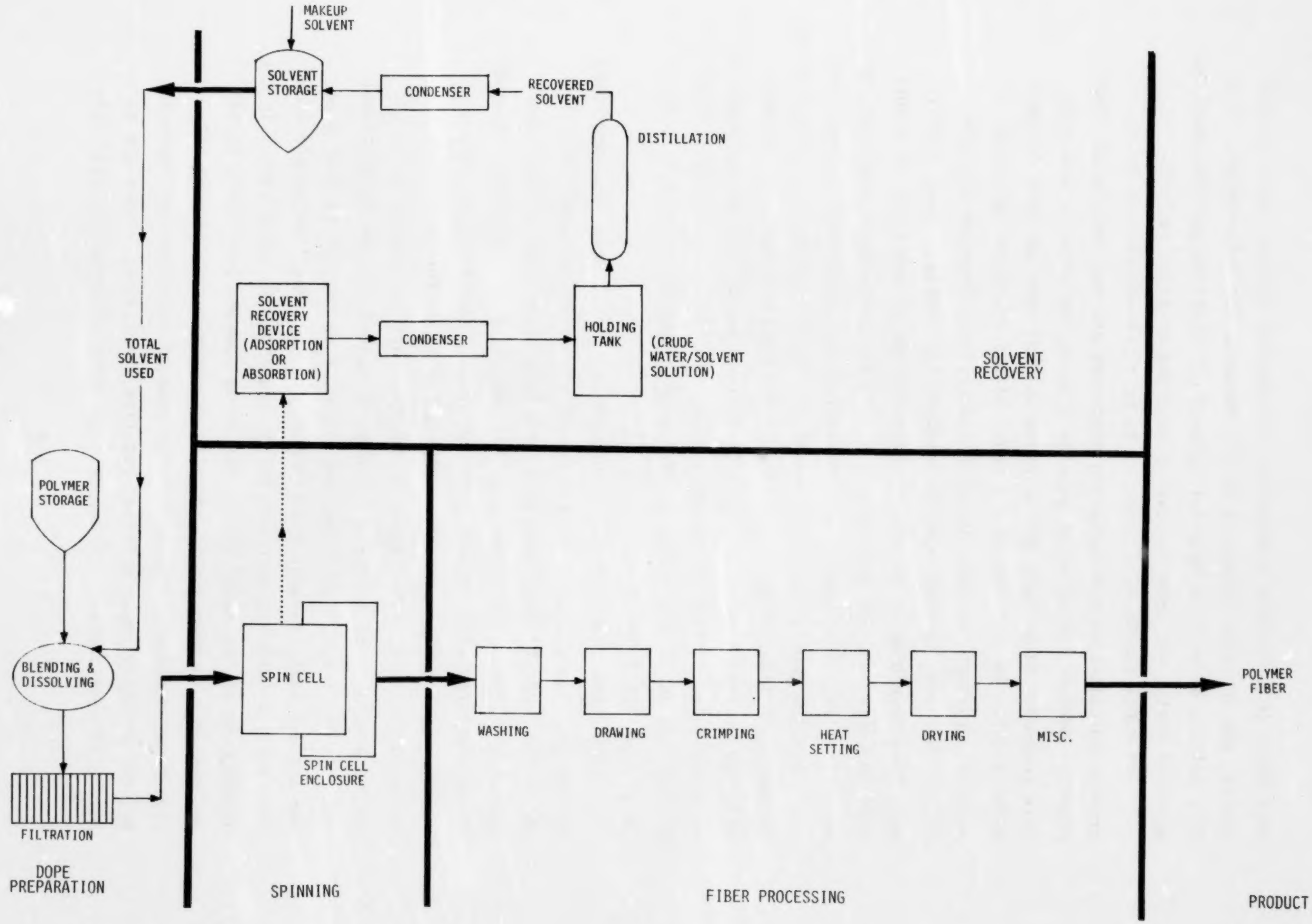
MAKEUP SOLVENT
SOLVENT STORAGE
CONDENSER
RECOVERED SOLVENT
DISTILLATION
TOTAL SOLVENT USED
SOLVENT RECOVERY DEVICE (ADSORPTION OR ABSORBTION)
CONDENSER
HOLDING TANK
(CRUDE WATER/SOLVENT SOLUTION)
SOLVENT RECOVERY
POLYMER STORAGE
BLENDING & DISSOLVING
FILTRATION
SPIN CELL
SPIN CELL ENCLOSURE
WASHING
DRAWING
CRIMPING
HEAT SETTING
DRYING
MISC.
POLYMER FIBER
DOPE PREPARATION
SPINNING
FIBER PROCESSING
PRODUCT

Figure 6-1. Generalized Flow Diagram for the Baseline Solvent Spinning Process

were based on published literature, information obtained during plant visits, and industry responses to EPA requests for information. This information, as well as material balance calculations and EPA-conducted emission tests, was used to develop baseline emission factors.

The model plants were selected to be representative of basic organic solvent-spun manufacturing processes and not individual fiber plants. However, in order to provide a basis for economic analysis, data regarding fiber type and spinning solvent were assigned to each model plant. In this regard the model plants represent wet-spun acrylic, dry-spun acrylic, dry-spun modacrylics, dry-spun acetate filter tow, and dry-spun acetate filament and staple. Model plants were then developed as parametric descriptions of the types of plants that in EPA's judgment are most likely to be constructed, modified, or reconstructed. The model plant parameters are summarized in Table 6-1.

As noted above, the model plants can be classified as representative of two basic fiber types: acrylic and modacrylic fibers, which cover all fibers consisting of at least 85 percent and 35 percent polymerized acrylonitrile, respectively; and cellulose acetate fibers, which cover all cellulosic fibers having a percentage of acetylation of 15 percent or greater (includes triacetate).

During the course of this study, model plants were also developed to characterize spandex fibers. Spandex is a manufactured fiber in which the fiber-forming substance is a long chain synthetic polymer comprised of at least 85 percent of a segmented polyurethane. Spandex is manufactured with two different processes domestically; one, a reaction-spinning process, is a substantially different process than any used for other fiber types by any manufacturer in the U.S. The second process used in the production of spandex is the conventional dry-spinning process which in some respects is similar to that used for acetate textile yarn; the fiber is dry spun and immediately wound onto take-up bobbins, then twisted or processed in other ways. In the development of the model plants for these spandex processes, it was not possible to identify technically demonstrated or economically viable methodology that conclusively reduced emissions (or improved solvent recovery) over existing baseline conditions. There are no more stringent control options or regulatory alternatives available

Table 6-1. BASELINE MODEL PLANT PARAMETERS

Model Plant Number	Production[a,b] Capacity Gg/Year	Production[a,b] Capacity (MMPPY)	Raw Materials (percent)	Total Solvent Used	Polymer Fiber Out	Make-up Solvent (kg/1000 kg Fiber)	Solvent Residual In Fiber (kg/1000 kg Fiber)	Misc. Solvent Losses (kg/1000 kg Fiber)	VOC Emissions (kg/1000 kg Fiber)
1[d] Acrylic Wet-Spin	45.36	100	98:2 PAN:MISC.[c]	3000 DMAc	1000 Acrylic	70 DMAc	5 DMAc	25[g] DMAc	40[h]
2 Acrylic Dry-Spin	45.36	100	98:2 PAN:MISC.	2200 DMF	1000 Acrylic	70 DMF	5 DMF	20 DMF	45[h]
3 Modacrylic Dry-Spin	20	44	98:2 PAN/Co-P:[e]MISC	2500 Acetone	1000 Modacrylic	155 Acetone	5 Acetone	10 Acetone	140
4 Acetate Filtration Tow Dry-Spin	22.7	50	98:2 CA:MISC.[f]	3000 Acetone	1000 CA	130 Acetone	Negligible	10 Acetone	120
5 Acetate Filament Yarn Dry-Spin	22.7	50	98:2 CA:MISC.	3000 Acetone	1000 CA	175 Acetone	10 Acetone	20 Acetone	145

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[a] Capacity utilization is a constant parameter equal to 95 percent for all model plants.

[b] Operating hours is a constant parameter equal to 8400 hours per year.

[c] Polyacrylonitrile (PAN).

[d] Included as a process variable is: Extrusion bath water = 2880 kg, H_2O.

[e] Copolymer (Co-P).

[f] Cellulose Acetate (CA).

[g] Includes distillation loss.

[h] Emission factor variation between acrylic and cellulose acetate fiber production is in large part due to the washing stage in the acrylic process which extracts residual solvent from the fiber. The step is not present in the modacrylic/cellulose acetate process.

for these fiber processes. This precludes the need for the development of an economic analysis for the spandex processes at this time. Therefore, the model plants and related information regarding the spandex processes were not included in this chapter of the BID but have been placed in the public docket for examination.[7-13]

It should be noted that in all model plant cases a solvent recovery system is included as an integral part of the process. This solvent recovery system is essential for the economic operation of all solvent-spun synthetic fiber production facilities.

6.2 REGULATORY ALTERNATIVES[14-29]

The purpose of this section is to define various regulatory alternatives or possible courses of action EPA could take to reduce VOC emissions from the synthetic fibers industry. The regulatory alternatives were developed following the study of the synthetic fibers industry and the available control techniques. Section 111 of the Clean Air Act, as amended, requires that standards of performance reflect the degree of emission control achievable through application of the best demonstrated technological system of continuous emission reduction which (taking into consideration the cost of achieving such emission reduction, any nonair quality health and environmental impact, and energy requirements) has been adequately demonstrated.

The most effective emission control technology currently used in the industry involves capture of a large portion of the solvent vapor generated during fiber manufacture by enclosing entire segments of the process line. The enclosures were originally designed and constructed in such a way as to minimize infiltration of solvent vapor into room air in order to prevent worker exposure as well as minimize the capture and unnecessary treatment of uncontaminated room air. This technology (referred to as Control Option A) can be applied to corresponding process stages in all wet and dry solvent-spun fiber manufacturing facilities. When applied to process stages which typically emit the largest amounts of solvent vapor (e.g., spin cell exits or fiber dryers), emission reductions from 31 to 47 percent below baseline are achieved. (Baseline refers to those emission levels which are expected to occur in the absence of additional control.) Furthermore, the technology can be extended to additional processing points (e.g., washing, drawing, crimping, etc.) to arrive at a more stringent control level for these facilities (referred to as Control Option B). An emission reduction of 60 to 76 percent beyond the baseline emission rate is expected using the extended control enclosure systems. Figures 6-2 and 6-3 present generalized schematics depicting these control options. In addition to solvent recovery, the plant can also indirectly control worker exposure to solvents and monomers with low threshold limit values (TLV's). Capture systems are not expected to interfere with the normal processing of the formed fiber or create any unusual operational or safety problems.

A different approach which has the potential of achieving similar levels of emission control (solvent recovery) has also been demonstrated in the fibers industry. In short, the system uses a plant ventilation or air management scheme in which air for the (post spinning) fiber take-up room is taken from the dope preparation and fiber processing areas. A fraction of the take-up room air is then used as spin cell evaporation gas and is subsequently sent to solvent recovery (carbon adsorption). Another fraction of the fiber take-up room air is used to dilute the high concentration process gas sent to solvent recovery. Since the level of control is dependent upon the amount of take-up room air sent directly to carbon adsorption, it is possible to achieve emission reductions similar to those involving the use of enclosures through optimization of the volume of room air treated. The air management system is used because the post spinning process steps for this fiber type are somewhat unique. The technology is feasible because the high Threshold Limit Value (TLV) for the solvent (acetone at a TLV of 1,000 ppm) allows the vapor concentration in the fiber extrusion (or take-up) room to reach a level that can be effectively treated. Some producers also use this control system with a combination of solvents. One solvent is used to produce one particular fiber type and another solvent or combination of solvents is used to produce a second fiber type within the same buildings. A mixture of volatilized solvents is captured and sent to a single control or recovery device. The individual solvents are then separated in the distillation stage. The only operational criteria for use of the air management scheme are

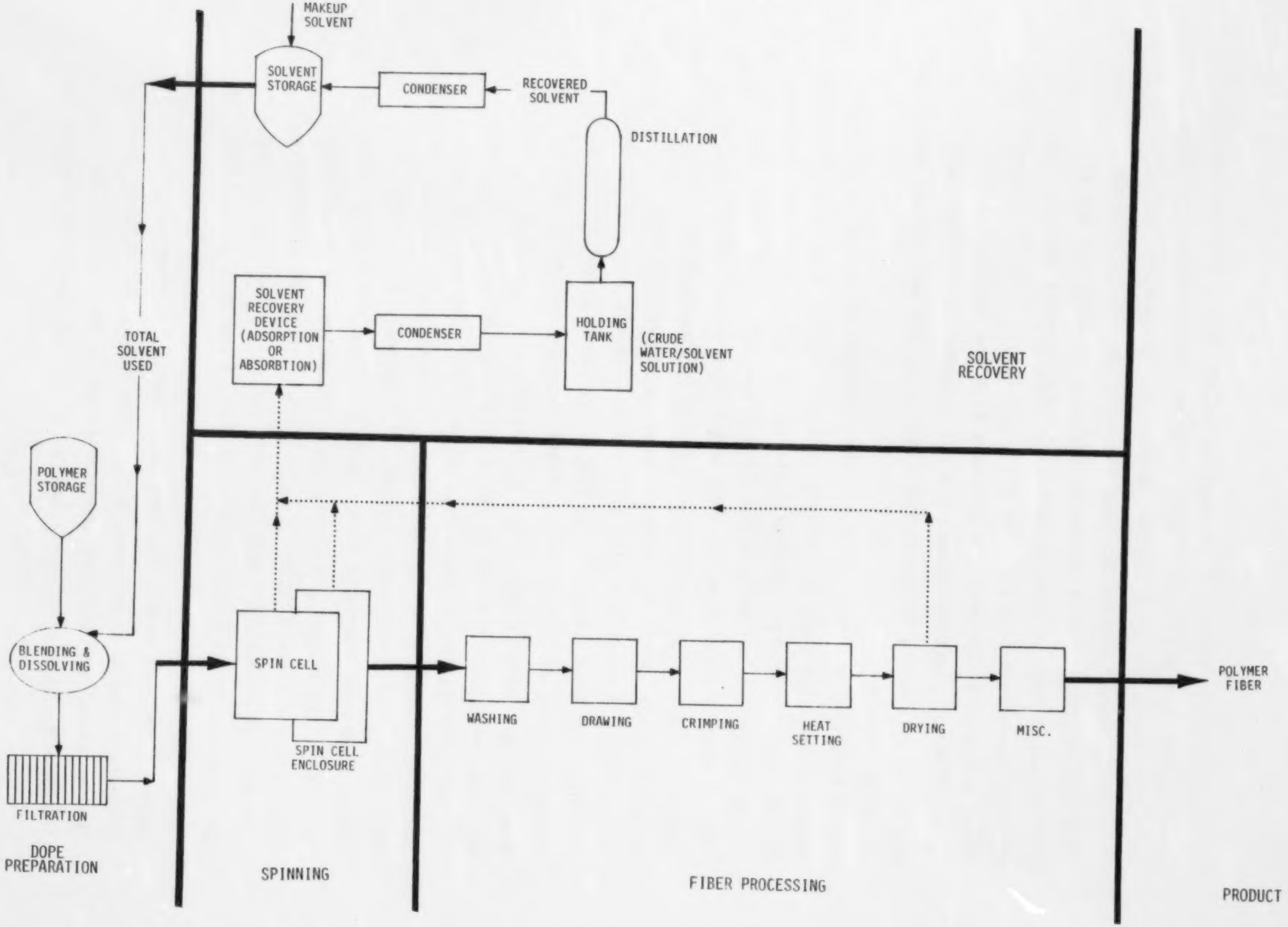
MAKEUP SOLVENT
SOLVENT STORAGE
CONDENSER
RECOVERED SOLVENT
DISTILLATION
TOTAL SOLVENT USED
SOLVENT RECOVERY DEVICE (ADSORPTION OR ABSORBTION)
CONDENSER
HOLDING TANK
(CRUDE WATER/SOLVENT SOLUTION)
SOLVENT RECOVERY
POLYMER STORAGE
BLENDING & DISSOLVING
SPIN CELL
WASHING
DRAWING
CRIMPING
HEAT SETTING
DRYING
MISC.
POLYMER FIBER
SPIN CELL ENCLOSURE
FILTRATION
DOPE PREPARATION
SPINNING
FIBER PROCESSING
PRODUCT

Figure 6-2. Generalized Flow Diagram for the Solvent Spinning Process Under Control Option A

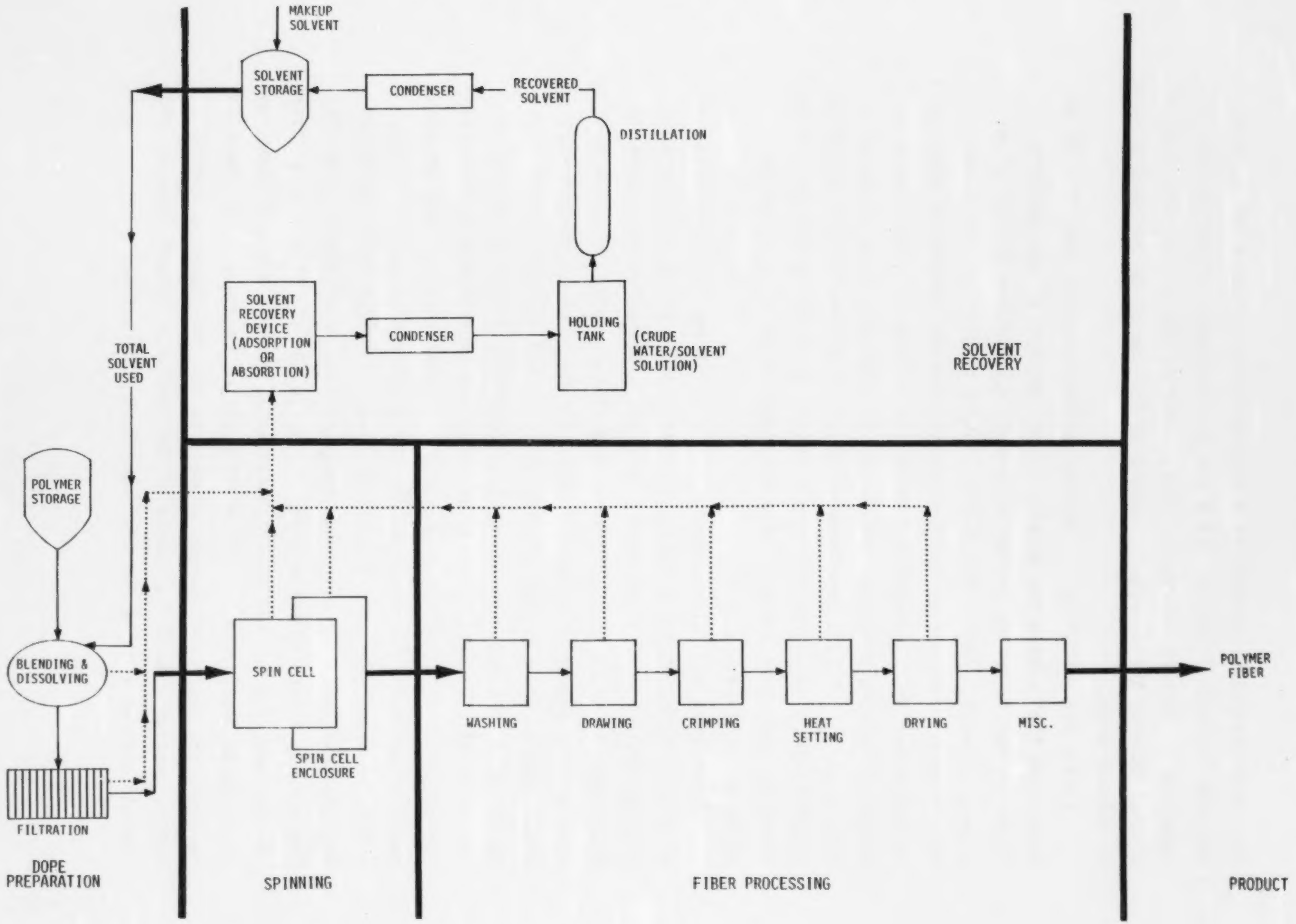
MAKEUP SOLVENT
SOLVENT STORAGE
CONDENSER
RECOVERED SOLVENT
DISTILLATION
SOLVENT RECOVERY DEVICE (ADSORPTION OR ABSORBTION)
CONDENSER
HOLDING TANK
(CRUDE WATER/SOLVENT SOLUTION)
SOLVENT RECOVERY
TOTAL SOLVENT USED
POLYMER STORAGE
BLENDING & DISSOLVING
FILTRATION
SPIN CELL
SPIN CELL ENCLOSURE
WASHING
DRAWING
CRIMPING
HEAT SETTING
DRYING
MISC.
POLYMER FIBER
DOPE PREPARATION
SPINNING
FIBER PROCESSING
PRODUCT

Figure 6-3. Generalized Flow Diagram for the Solvent Spinning Process Under Control Option B

that each solvent be present at a concentration suitable for capture and that individual solvent TLV's are not exceeded. A significant reduction in solvent TLV would likely restrict the use of this type of control scheme; the alternative would be the use of an enclosed winding or take-up area.

During the investigation of the synthetic fibers industry, it was determined that within the acrylic fibers segment of the industry there are manufacturing processes that do not involve the use of an organic solvent. Although a viable control option for some plants, this inorganic solvent production process was not considered applicable to the entire fibers industry. There are no readily identifiable inorganic solvent processes available for some acrylic or modacrylic fibers; acrylic fibers manufactured using an organic solvent spinning process cannot be reproduced exactly using inorganic processes. Also, inorganic processes are available for other fiber types, such as cellulose acetate.

There were also other reasons for eliminating its consideration as a control option for the proposed standards. While the inorganic process would result in an almost complete elimination of solvent VOC emissions, it would also generate a significant water pollution problem. Further, the inorganic solvent process (or portions of the process) is under patent, and a number of complex legal and economic issues could be raised if the proposed standards effectively forced a company to use a specific process that may be owned and protected by a competitor. The mutual competitive positions of the several acrylic fiber producers would be substantially altered, and their customers (textile firms, carpet manufacturers, etc.) would be forced to alter their processes and products to accommodate what would in fact be different products. The acrylic fibers produced using the large variety of processes have certain specific but different characteristics that are well known and expected by the purchasers for quality control reasons. For these reasons, the inorganic solvent process is not considered a control option available to all segments of the synthetic fibers industry and was not used as a basis for any regulatory alternative.

Table 6-2 presents baseline emissions and summarizes the total VOC emissions from each model plant. Also presented are the emission rates and percent emission reduction associated with Control Options A and B.

The baseline controlled model plants and Control Options A and B provide the basis for three regulatory alternatives available to EPA for regulation of VOC emissions from wet and dry solvent-spun fiber plants. The three alternatives are based on emission control techniques representative of three distinct levels of control. Table 6-3 summarizes these alternatives and the control options available to the industry to achieve each level.

Alternative I, referred to as baseline, is equivalent to no additional regulatory action. For this alternative, VOC emission levels would be the same as those currently achieved. It is important to note that there are no State or local emission regulations which apply specifically to the production of man-made fibers, nor is there a Control Techniques Guideline (CTG) recommended emission limit. Of the eight States containing fiber production facilities, most employ a ceiling or guideline regulating VOC's which is similar to California's Rule 66. Economic incentives rather than regulatory requirements, however, dictate recovery of the solvents used in the processes. Therefore, the VOC emission levels represented in Alternative I (with the exception of Model Plant 2) reflect typical industry control practices rather than levels imposed by regulations. Baseline control for Model Plant 2 reflects expected or average control levels. A new dry-spun acrylic manufacturing facility might not necessarily control solvent VOC emissions to the extent now controlled by the only current dry-spun acrylic manufacturer.

Alternative II is based on Control Option A and requires the use of efficient vapor capture systems for process stages other than the actual spinning step (i.e., spin cell exits and dryer exhausts) or the recirculation of a portion of room air to the process. Regulatory Alternative III is based on Control Option B which extends the capture and collection systems to additional processing points (e.g., washing, drawing, crimping, heat setting, etc.) in the case of line enclosures and to increased air volumes in the case of air management.

Table 6-2. EMISSION FACTORS FOR BASELINE AND CONTROL OPTIONS A AND B

Model Plant	Baseline kg VOC/Mg Polymer (kg VOC/Mg Solvent)	Emissions with Option A Controls[a,b] kg VOC/Mg Polymer (kg VOC/Mg Solvent)	Percent Reduction Beyond Baseline	Emissions with Option B Controls[a,b] kg VOC/Mg Polymer (kg VOC/Mg Solvent)	Percent Reduction Beyond Baseline
1 Acrylic Wet-Spun	40 (14)	26 (9)	35	13 (5)	68
2 Acrylic Dry-Spun	45 (21)	31 (14)	31	18 (8)	60
3 Modacrylic Dry-Spun	140 (56)	86 (35)	39	33 (14)	76
4 Acetate Filtration Tow Dry-Spun	120 (40)	67 (22)	44	44 (15)	63
5 Acetate Filament Dry-Spun	145 (49)	66 (22)	55	40 (14)	72

[a] Assuming a 90 percent capture efficiency and a 98 percent control device efficiency for Model Plants 1-4, Control Options A and B.

[b] No capture efficiency is used in Model Plant 5, Control Options A and B; a 95 percent control device efficiency is used for the control options.

Table 6-3. SUMMARY OF CONTROL OPTIONS AND REGULATORY ALTERNATIVES

Alternatives	Reduction Beyond Baseline (percent)	Available Control Option
I No Regulation	--	Baseline Control
II Add-on Controls	31 - 55	Control Option A
III Add-on Controls	60 - 76	Control Option B

6.3 ACRYLIC FIBER MODEL PLANTS AND REGULATORY ALTERNATIVES[30-40]

Polyacrylonitrile resins used to make acrylic and modacrylic fibers are produced by suspension or solution polymerization. Either batch or continuous reaction modes may be employed, and either wet or dry spinning may be used to form the fibers. In addition, a variety of spinning solvents are used by industry. These include organic solvents such as dimethylformamide (DMF), dimethylacetamide (DMAc) or acetone and aqueous solutions of acids or salts such as zinc chloride and sodium thiocyanate.

In an attempt to accurately represent the acrylic fibers industry through definition of model plant parameters, three separate model plants are presented. The three model plants are characterized according to the process techniques presented in Table 6-4.

Table 6-4. ACRYLIC FIBER PROCESS TECHNIQUES

Model Plant Number	Polymerization Medium	Polymerization Operation	Spinning Process	Spinning Solvent
1	Suspension or Solution	Batch or Continuous	Wet	Organic solvent, DMAc
2	Suspension or Solution	Batch or Continuous	Dry	Organic solvent, DMF
3	Suspension	Continuous	Dry	Organic solvent, Acetone

6.3.1 Model Plant 1

6.3.1.1 Regulatory Alternative I, Baseline Control. This plant is characterized by use of suspension or solution polymerization and wet spinning with an organic solvent. The model plant block or schematic diagram is presented in Figure 6-4; Table 6-5 presents the relevant model plant parameters. Major emission points, for wet spun acrylic fibers, are the filtration, spinning, washing, drying, and crimping steps where solvent is volatilized in room air. The diagram includes identification of the major emission points which are normally vented directly to the atmosphere. This plant represents the processes and

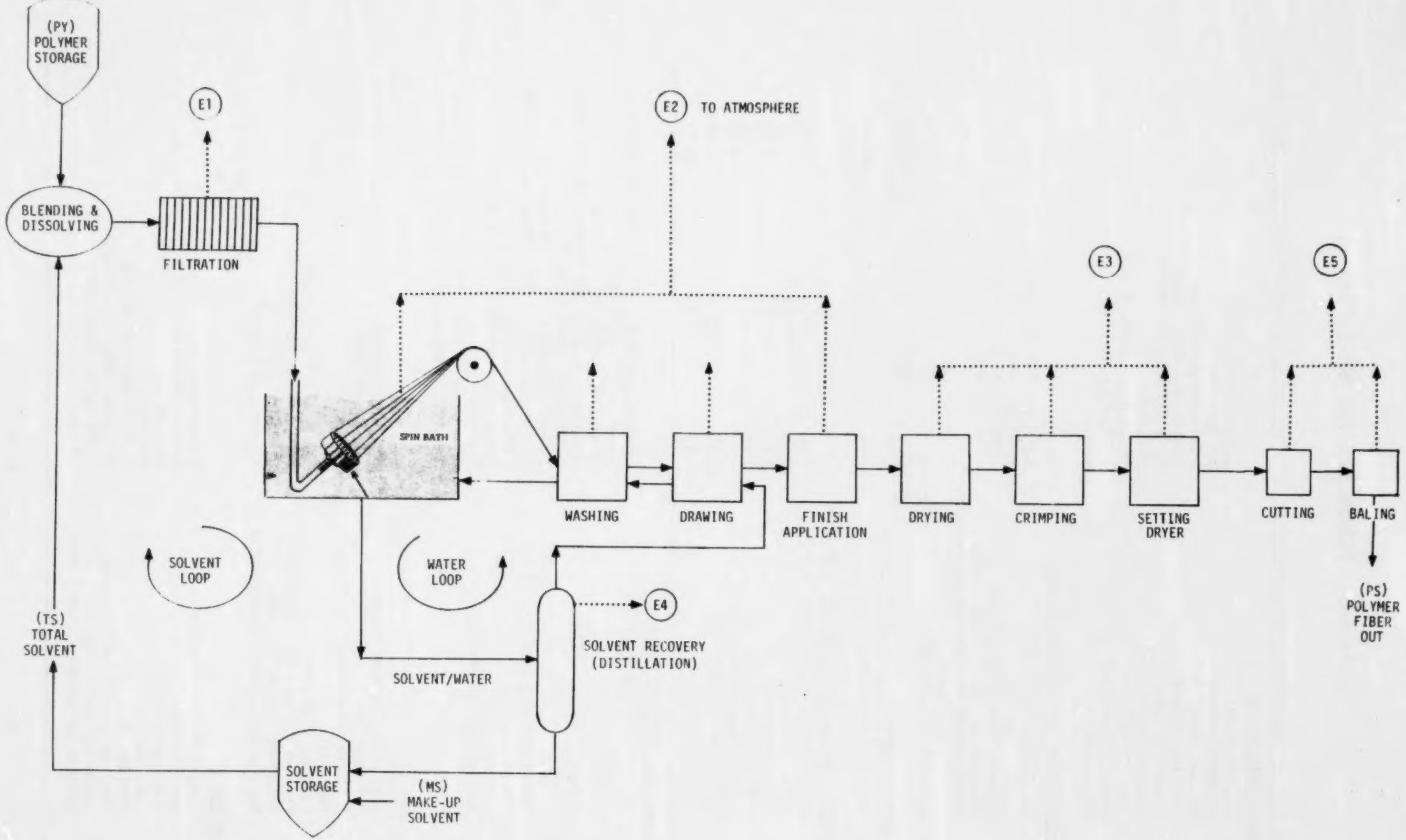
(PY) POLYMER STORAGE
BLENDING & DISSOLVING
FILTRATION
E1
E2
TO ATMOSPHERE
SPIN BATH
WASHING
DRAWING
FINISH APPLICATION
DRYING
CRIMPING
SETTING DRYER
CUTTING
BALING
E3
E5
(PS) POLYMER FIBER OUT
SOLVENT LOOP
WATER LOOP
E4
SOLVENT RECOVERY (DISTILLATION)
SOLVENT/WATER
(TS) TOTAL SOLVENT
SOLVENT STORAGE
(MS) MAKE-UP SOLVENT

Figure 6-4. Acrylic Fiber Wet Spinning Baseline Control, Model Plant 1

Table 6-5. PARAMETERS FOR MODEL PLANT 1

General Information	
Type of Plant	Acrylic Fibers Plant
Spinning Process	Wet Spinning
Polymerization Medium	Suspension or solution
Spinning Solvent	Dimethylacetamide (DMAc)
Production Capacity	45.36 Gg/Year (100 MMPPY)
Capacity Utilization	95 percent
Raw Materials	Polyacrylonitrile, 98 percent
Hours of Operation	8,400 hours per year
Pollutants	DMAc
Process Rates (Per 1,000 kg fiber)	
Raw Materials In (PY)	1,000 kg, PAN, 20 kg other materials
Solvent Use (TS)	3,000 kg, DMAc
Polymer Fiber Produced (PS)	1,000 kg, Acrylic Fiber
Residual Solvent in Fiber (RS)	5 kg, DMAc
Miscellaneous Non-Gaseous Solvent Loss (Includes Distillation Loss)	25 kg, DMAc

Process Variables (Per 1,000 kg fiber)	Alternative I (Baseline)	Alternative II (Control Option A)	Alternative III (Control Option B)
Make-up Solvent (MS)	70 kg	56 kg	43 kg
Emission Sources (Per 1,000 kg fiber)			
Filtering/Dissolving (E1)	1 kg	1 kg	1 kg
Spinning/Washing (E2)	15 kg	1 kg	1 kg
Crimping/Drying (E3)	15 kg	15 kg	1 kg
Cutting/Baling (E5)	1 kg	1 kg	1 kg
Solvent Recovery Area (E4)	3 kg	3 kg	4 kg
Miscellaneous Fugitives	5 kg	5 kg	5 kg
Emission Totals	40 kg	26 kg	13 kg

Exhaust Gas Characteristics	
Filtering/Dissolving (E1)	Intermittent Flow: 140 M^3/Min (5,000 ACFM) Temperature: 27°C (80°F) Solvent Concentration: 25 ppmv
Spinning/Washing (E2)	Continuous Flow: 4,250 M^3/Min (150,000 ACFM) Temperature: 50°C (120°F) Solvent Concentration: 100 ppmv
Crimping/Drying (E3)	Continuous Flow: 1,700 M^3/Min (60,000 ACFM) Temperature: 82°C (180°F) Solvent Concentration: 250 ppmv
Cutting/Baling Area (E5)	Fugitives Temperature: 27°C (80°F) Solvent Concentration: 5 ppmv
Scrubber #1	
Controlled Emission Source	Spinning/Washing
Scrubber Type	Bubble cap tower
Scrubber Efficiency	98+ percent
Feed Gas	Air/DMAc
Feed Gas Flow Rate	570 M^3/Min (20,000 ACFM)
Feed Gas Solvent Concentration	650 ppm DMAc (1.2 kg/min)
Scrubbing Liquid Flow Rate	500 kg/hr D.M. water
Residue Gas Solvent Concentration	15 ppm (.02 kg/min)
Scrubber #2	
Controlled Emission Source	Crimping/Drying
Scrubber Type	Bubble cap tower
Scrubber Efficiency	98+ percent
Feed Gas	Air/DMAc
Feed Gas Flow Rate	1,700 M^3/Min (60,000 CFM)
Feed Gas Solvent Concentration	250 ppmv, DMAc (1.2 kg/min)
Scrubbing Liquid Flow Rate	2,000 kg/hr, D.M. water
Residue Gas Solvent Concentration	15 ppmv

air pollution emission control technology currently in-use in this particular segment of the acrylic fibers industry. This particular production or process sequence is considered as "baseline control."

For a wet-spinning capacity of 45.36 Gg (100 MMPPY), it is assumed that eight spin baths, each 3m x 5m, and eight washers, each 3m x 15m, are needed together with appropriate fiber processing equipment to complete the eight spinning lines. The process lines are essentially open to room air. Ventilation hoods are located above the spinning and washing areas and at various other major processing points. The existing ventilation systems are designed around high air flow rates with little emphasis on enclosures to reduce air volume flow.

6.3.1.2 Regulatory Alternative II, Control Option A. Since major VOC emissions for this production sequence occur at spinning and washing, an option for VOC emission control is to enclose these process steps; the collected gases are then directed to a solvent recovery scrubber. The enclosures would be reasonably tight in order to limit the volume of gas to be treated. The enclosures would be sufficient to cover the equipment, tied together with proper manifolding, and equipped with doors at the correct spacing to permit operator access. The enclosures would be tight enough to restrict the air flow to about 20,000 SCFM. If a flow of 20,000 SCFM is used, the VOC concentration can be maintained well below the solvent lower explosive limit (1.8 percent by volume). With a capture efficiency of 90 percent and a solvent recovery (absorption/stripping) efficiency of 98 percent, the emission reduction would amount to about 14 kg per 1,000 kg of polymer fiber. Use of a solvent scrubber to treat gas streams from spinning, washing, drawing, and drying would reduce VOC emissions and recover additional spinning solvent. Figure 6-5 provides a schematic diagram of this control option as applied to Model Plant 1. Table 6-5 contains the model plant parameters for this option. Figure 6-6 shows the enclosures in isometric and in plan and elevation views.

6.3.1.3 Regulatory Alternative III, Control Option B. This control option incorporates the VOC control measures outlined in Option A and includes the additional control of the emissions from the filtering, crimping, and/or steam setting dryer. These processes, which are normally vented directly to the atmosphere, would be collected, and the exhaust gas stream would then be vented to a solvent recovery

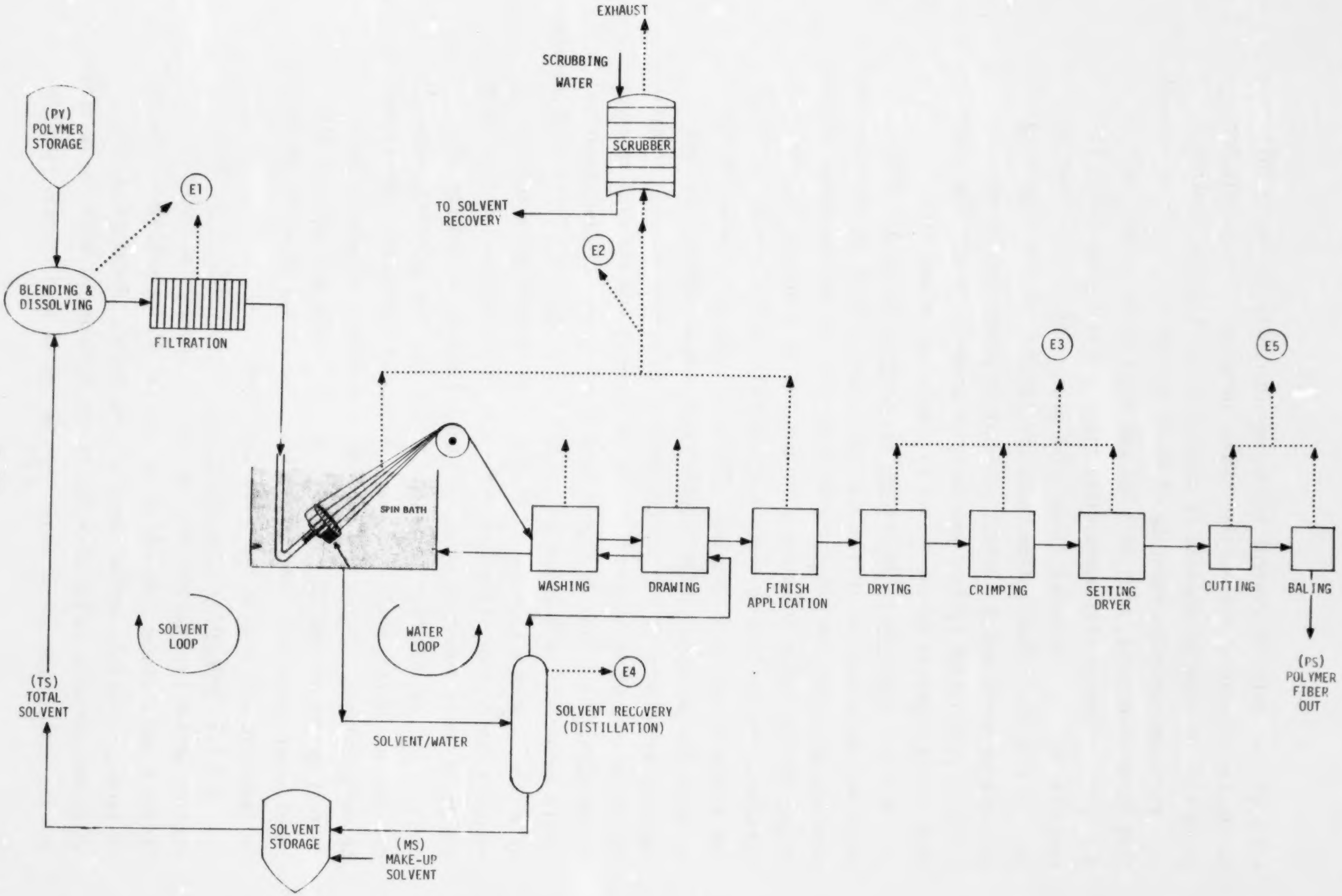
EXHAUST
SCRUBBING WATER
SCRUBBER
TO SOLVENT RECOVERY
(PY) POLYMER STORAGE
E1
BLENDING & DISSOLVING
FILTRATION
E2
E3
E5
SPIN BATH
WASHING
DRAWING
FINISH APPLICATION
DRYING
CRIMPING
SETTING DRYER
CUTTING
BALING
(PS) POLYMER FIBER OUT
SOLVENT LOOP
WATER LOOP
E4
(TS) TOTAL SOLVENT
SOLVENT RECOVERY (DISTILLATION)
SOLVENT/WATER
SOLVENT STORAGE
(MS) MAKE-UP SOLVENT

Figure 6-5. Regulatory Alternative II for Model Plant 1, Acrylic Fiber Wet Spinning

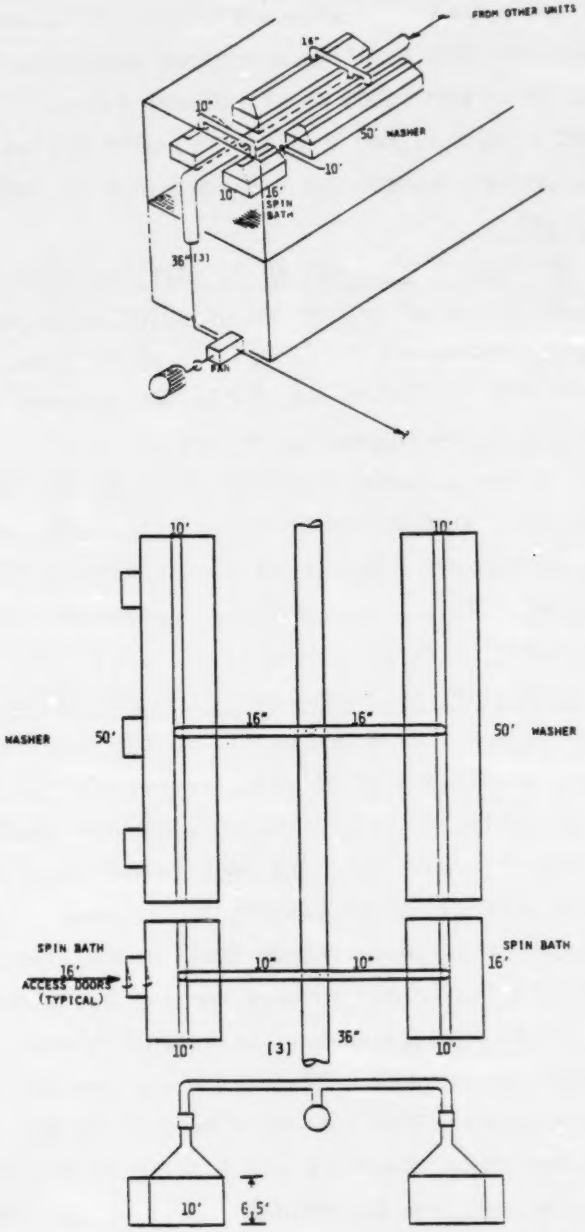
FROM OTHER UNITS
16"
10"
50' WASHER
10'
10'
16'
SPIN
BATH
36" [3]
FAN
10'
10'
WASHER
50'
16"
16"
50'
WASHER
SPIN BATH
16'
ACCESS DOORS
(TYPICAL)
10"
10"
SPIN BATH
16'
10'
[3]
36"
10'
10'
6.5'

Figure 6-6. Ducts and Enclosures for Acrylic Fibers Spinning and Washing Steps

scrubber similar to the one described in Option A. The total gas volume flow would be about 60,000 ACFM. Assuming a capture efficiency of 90 percent and a control device efficiency of 98 percent, the emissions reduction from baseline emissions resulting from Option B would be about 27 kg per 1,000 kg of polymer fiber. Figure 6-7 presents the model plant schematic for this process with Option B applied. Details on the process parameters are contained in Table 6-5.

6.3.2 Model Plant 2

6.3.2.1 Regulatory Alternative I, Baseline Control. This plant is characterized by use of suspension or solution polymerization and dry spinning with an organic solvent. The model plant block or schematic diagram is presented in Figure 6-8; Table 6-6 presents the parameters and technical details corresponding to the dry spinning model plant schematic. For a dry spinning capacity of 45.36 Gg (100 MMPPY), four spinning lines, each with 50 spinning cells per side, are needed together with appropriate fiber processing equipment to complete the model plant layout. This plant sequence represents "baseline control" for the dry spinning of acrylic fibers.

6.3.2.2 Regulatory Alternative II, Control Option A. The spinning, washing, steaming, and drying processes are the major VOC emission sources in the dry spinning of acrylic fibers. Option A for this process involves collecting the spinning emissions (solvent volatilized as the fibers exit the spin cell and move to the processing stages) with appropriate enclosures and venting the solvent containing gases to a solvent recovery scrubber rather than to the atmosphere. If a flow of 15,000 ACFM (spinning) is used for the gas stream, the solvent concentration can be maintained well below the solvent lower explosive limit (2.2 percent by volume). Assuming a capture efficiency of 90 percent and a recovery/control efficiency of 98 percent, the VOC emission reduction would amount to about 14 kg of VOC per 1,000 kg of polymer fiber produced from the spinning cell exits. Total solvent recovered from Option A control would also be about 14 kg per 1,000 kg of polymer. Figure 6-9 provides the schematic diagrams of this control option as applied to Model Plant 2. Table 6-6 lists the appropriate parameters for this control option in relation to the schematic diagrams.

6.3.2.3 Regulatory Alternative III, Control Option B. This control option for the dry spinning of acrylics includes capture and treatment of the steaming and drying process steps exhaust gases as

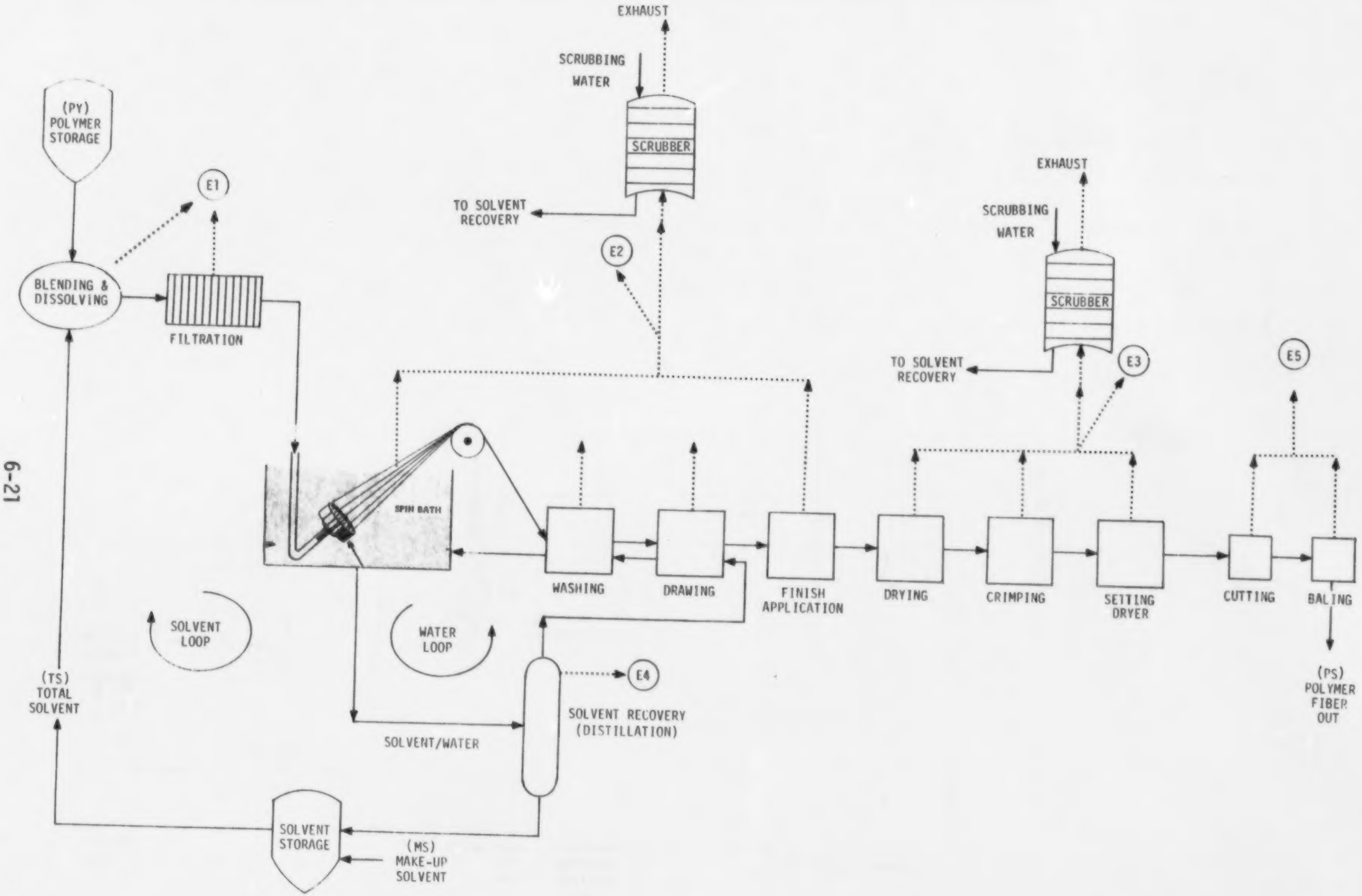
EXHAUST
SCRUBBING WATER
SCRUBBER
TO SOLVENT RECOVERY
(PY) POLYMER STORAGE
E1
E2
BLENDING & DISSOLVING
FILTRATION
EXHAUST
SCRUBBING WATER
SCRUBBER
TO SOLVENT RECOVERY
E3
E5
SPIN BATH
WASHING
DRAWING
FINISH APPLICATION
DRYING
CRIMPING
SETTING DRYER
CUTTING
BALING
SOLVENT LOOP
WATER LOOP
E4
SOLVENT RECOVERY (DISTILLATION)
(TS) TOTAL SOLVENT
SOLVENT/WATER
(PS) POLYMER FIBER OUT
SOLVENT STORAGE
(MS) MAKE-UP SOLVENT

Figure 6-7. Regulatory Alternative III for Model Plant 1, Acrylic Fibers Wet Spinning

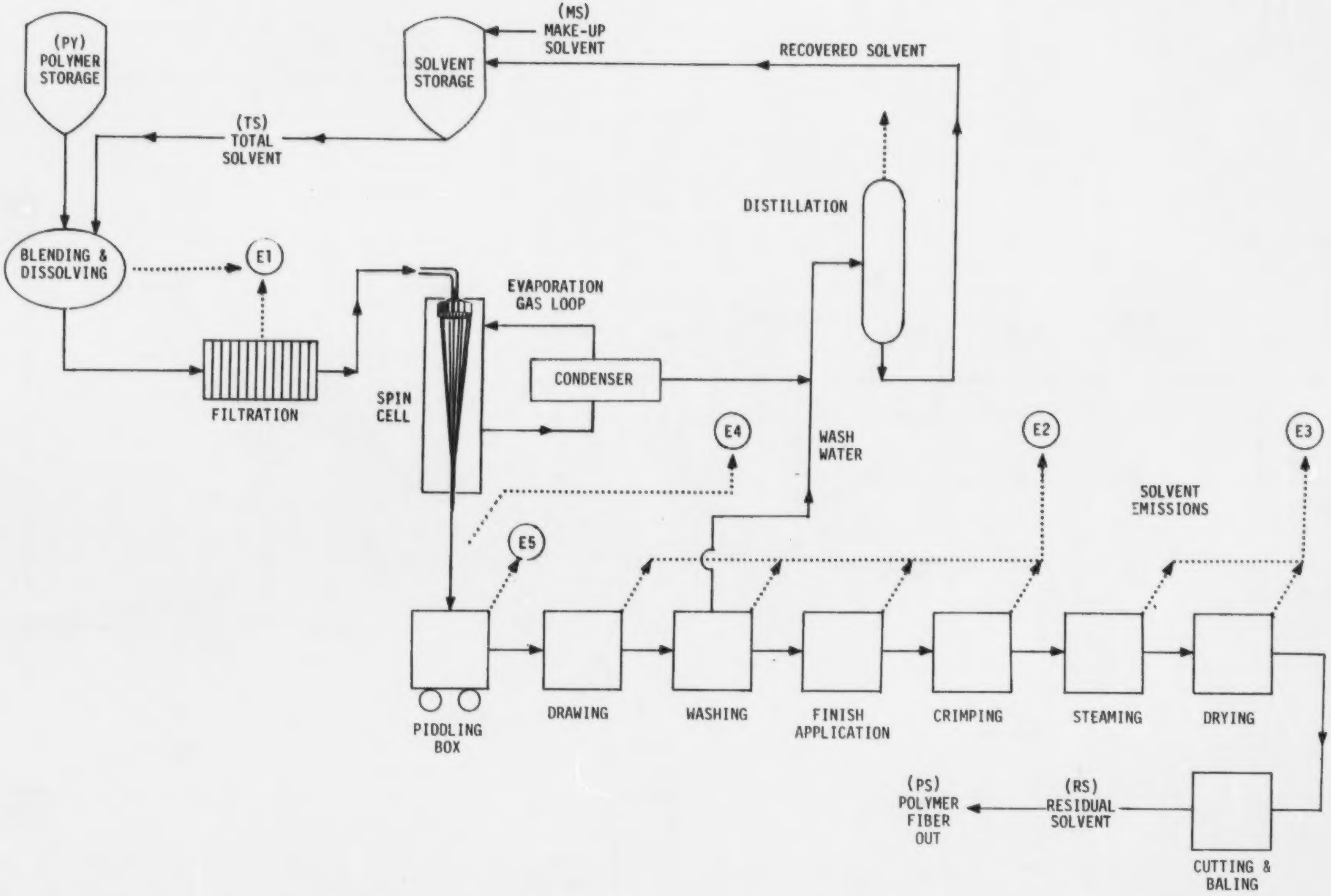
(PY)
POLYMER
STORAGE
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
RECOVERED SOLVENT
(TS)
TOTAL
SOLVENT
DISTILLATION
BLENDING &
DISSOLVING
E1
EVAPORATION
GAS LOOP
CONDENSER
FILTRATION
SPIN
CELL
E4
WASH
WATER
E2
E3
SOLVENT
EMISSIONS
E5
PIDDLING
BOX
DRAWING
WASHING
FINISH
APPLICATION
CRIMPING
STEAMING
DRYING
(PS)
POLYMER
FIBER
OUT
(RS)
RESIDUAL
SOLVENT
CUTTING &
BALING

Figure 6-8. Acrylic Fibers Dry Spinning Baseline Control, Model Plant 2

Table 6-6. PARAMETERS FOR MODEL PLANT 2

General Information	
Type of Plant	Acrylic Fibers Plant
Spinning Process	Dry Spinning
Polymerization Medium	Suspension or solution
Spinning Solvent	Dimethylformamide (DMF)
Production Capacity	45.36 Gg/Year (100 MMPPY)
Capacity Utilization	95 percent
Raw Materials	Polyacrylonitrile, 98%, 2% other material
Hours of Operation	8,400 hours per year
Pollutants	DMF
Process Rates (Per 1,000 kg fiber)	
Raw Materials In (PY)	1,000 kg, PAN, 20 kg other materials
Solvent Use (TS)	2,200 kg, DMF
Polymer Fiber Produced (PS)	1,000 kg, Acrylic Fiber
Residual Solvent in Fiber (RS)	5 kg, DMF
Miscellaneous Non-Gaseous Solvent Loss	20 kg, DMF

Process Variables (Per 1,000 kg fiber)	Alternative I (Baseline)	Alternative II (Control Option A)	Alternative III (Control Option B)
Make-up Solvent (MS)	70 kg	56 kg	42 kg
Emission Sources (Per 1,000 kg fiber)			
Filtering/Dissolving (E1)	1 kg	1 kg	1 kg
Spin Cell Exits (E4)	15 kg	1 kg	1 kg
Wash/Draw/Crimp (E2)	2 kg	2 kg	2 kg
Piddle/Waste System (E5)	6 kg	6 kg	6 kg
Steaming/Drying (E3)	15 kg	15 kg	1 kg
Solvent Recovery Area	1 kg	1 kg	2 kg
Miscellaneous Fugitives	5 kg	5 kg	5 kg
Emission Totals	45 kg	31 kg	18 kg

Exhaust Gas Characteristics	
Filtering/Dissolving (E1)	Intermittent Flow: 140 M^3/Min (5,000 ACFM) Temperature: 38°C (100°F) Solvent Concentration: 10 ppmv
Spin Cell Exits (E4)	Continuous Flow: fugitive emissions Temperature: 38°C (100°F) Solvent Concentration: Variable
Steaming/Drying (E3)	Continuous Flow: 1,700 M^3/Min (60,000 ACFM) Temperature: 82°C (180°F) Solvent Concentration: 300 ppmv
Wash/Draw/Crimp (E2)	Continuous Flow: 5,700 M^3/Min (200,000 ACFM) Temperature: 38°C (100°F) Solvent Concentration: 10 ppmv
Scrubber #1	
Controlled Emission Source	Spinning (E4)
Scrubber Type	Bubble cap tower
Scrubber Efficiency	98+ percent
Feed Gas	Air/DMF
Feed Gas Flow Rate	425 M^3/Min (15,000 ACFM)
Feed Gas Solvent Concentration	1,000 ppm DMF (1.3 kg/min)
Scrubbing Liquid Flow Rate	400 kg/hr D.M. water
Residue Gas Solvent Concentration	20 ppm (.03 kg/min) DMF
Scrubber #2	
Controlled Emission Source	Streaming/Drying (E3)
Scrubber Type	Bubble cap tower
Scrubber Efficiency	98+ percent
Feed Gas	Air/DMF
Feed Gas Flow Rate	1,700 M^3/Min (60,000 CFM)
Feed Gas Solvent Concentration	300 ppmv, DMF (1.28 kg/min)
Scrubbing Liquid Flow Rate	2,000 kg/hr, D.M. water
Residue Gas Solvent Concentration	10 ppmv DMF (0.02 kg/min)

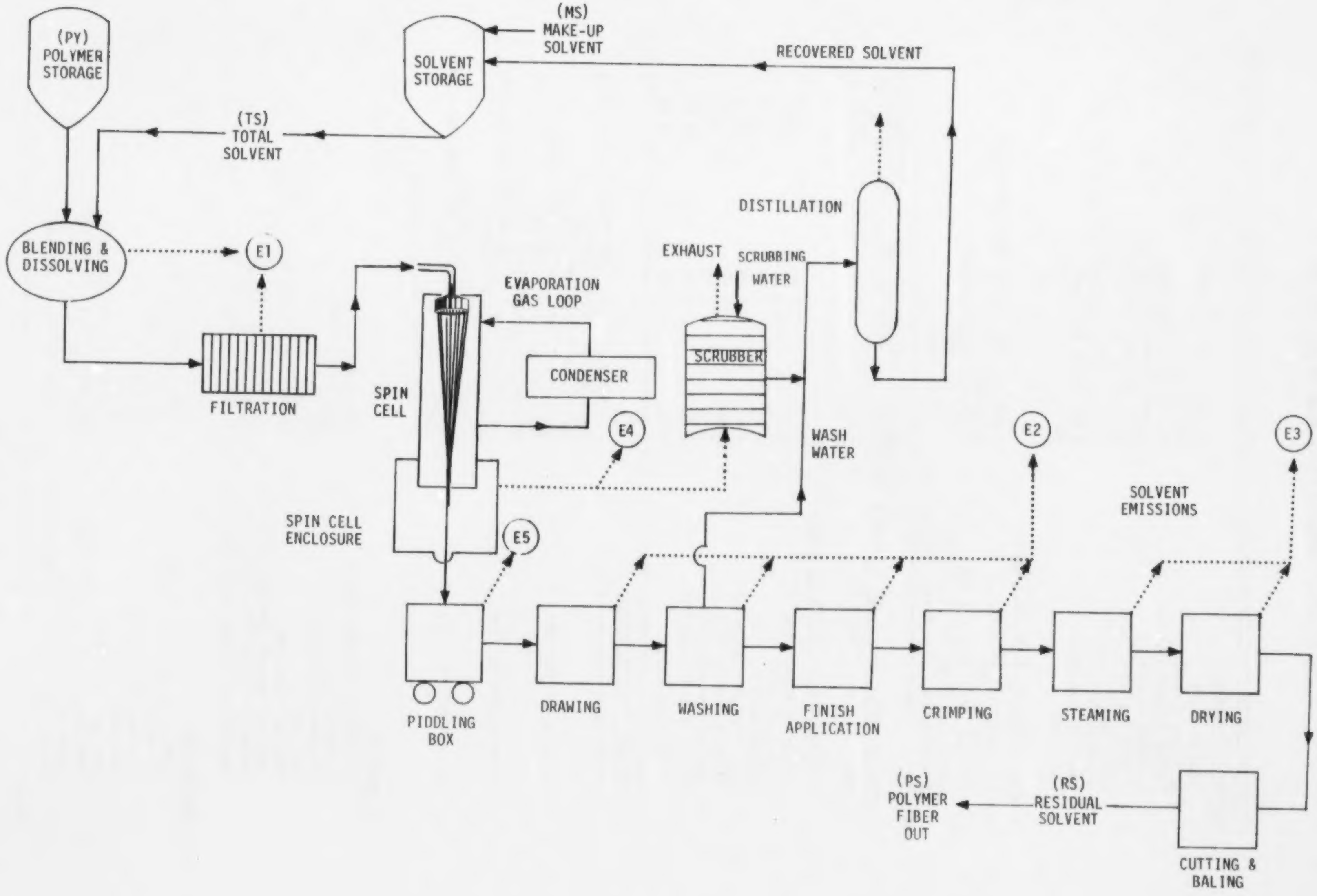
(PY)
POLYMER
STORAGE
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
RECOVERED SOLVENT
(TS)
TOTAL
SOLVENT
DISTILLATION
BLENDING &
DISSOLVING
E1
EXHAUST
SCRUBBING
WATER
EVAPORATION
GAS LOOP
SCRUBBER
CONDENSER
FILTRATION
SPIN
CELL
E4
WASH
WATER
E2
E3
SOLVENT
EMISSIONS
SPIN CELL
ENCLOSURE
E5
PIDDLING
BOX
DRAWING
WASHING
FINISH
APPLICATION
CRIMPING
STEAMING
DRYING
(PS)
POLYMER
FIBER
OUT
(RS)
RESIDUAL
SOLVENT
CUTTING &
BALING

Figure 6-9. Regulatory Alternative II for Model Plant 2, Acrylic Fibers Dry Spinning

well as those from the spinning cell walls. The total exhaust gas stream from the steaming and drying stages would be vented to a solvent recovery scrubber similar to the one described in Option A. The enclosures on these process stages would be reasonably tight in order to limit the fugitive losses. If a flow of 60,000 CFM is used to characterize the combined exhaust gas stream, solvent concentrations are maintained well below the lower explosive limit (0.2 percent by volume). The dryer air flow rate is related directly to product quality control and, as a process variable, cannot be reduced to increase the solvent concentration. Assuming a capture efficiency of about 90 percent at the steaming/drying stage and a control device efficiency of 98 percent, the total VOC emission reduction measured from baseline control resulting from application of Option B controls would be about 27 kg of VOC per 1,000 kg of fiber. Figure 6-10 presents the model plant schematic for this model plant with Option B applied. Details on the process parameters are contained in Table 6-6.

6.3.3 Model Plant 3[41-50]

6.3.3.1 Regulatory Alternative I, Baseline Control. This model plant is based on suspension polymerization and dry spinning with acetone as the organic solvent. The processing or manufacturing stages are quite similar to those of the preceding model plants. Polymer (or copolymers) is dissolved in solvent, blended, filtered, dry spun, drawn, washed, crimped, and dried. For this segment of the acrylic fiber industry, a model plant capacity of 20 Gg per year (44 MMPPY) was selected. For this dry spinning capacity, two spinning lines, each with 50 spinning cells per side, are required as well as the appropriate downstream fiber processing equipment.

The major emissions from this dry spinning process are volatilized solvent losses which occur at a number of points in the overall production scheme. Solvent emissions occur during dissolving of the polymer, blending of the spinning solution, filtering of the dope, spinning of the fiber, treating of the fiber after spinning, and during the solvent recovery process. Figure 6-11 presents a process flow diagram, with emission points shown, for this segment of the acrylic fibers industry. Table 6-7 includes the model plant parameters relevant to the diagram. This production or process sequence is considered as "baseline control" for this model plant.

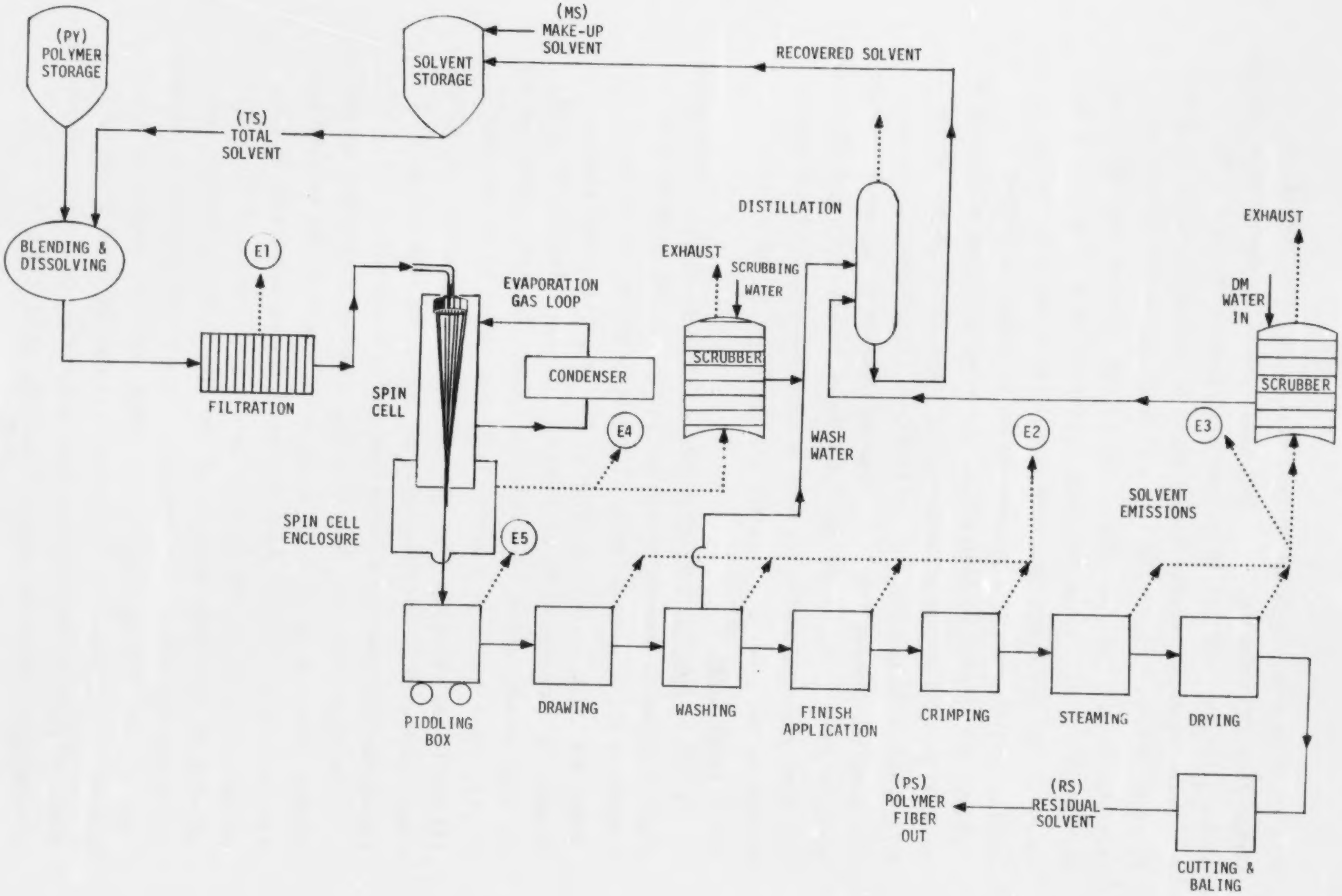
(PY)
POLYMER
STORAGE
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
RECOVERED SOLVENT
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
E1
FILTRATION
SPIN
CELL
EVAPORATION
GAS LOOP
CONDENSER
E4
SPIN CELL
ENCLOSURE
E5
EXHAUST
SCRUBBING
WATER
SCRUBBER
DISTILLATION
WASH
WATER
E2
EXHAUST
DM
WATER
IN
SCRUBBER
E3
SOLVENT
EMISSIONS
PIDDLING
BOX
DRAWING
WASHING
FINISH
APPLICATION
CRIMPING
STEAMING
DRYING
(PS)
POLYMER
FIBER
OUT
(RS)
RESIDUAL
SOLVENT
CUTTING &
BALING

Figure 6-10. Regulatory Alternative III for Model Plant 2, Acrylic Fibers Dry Spinning

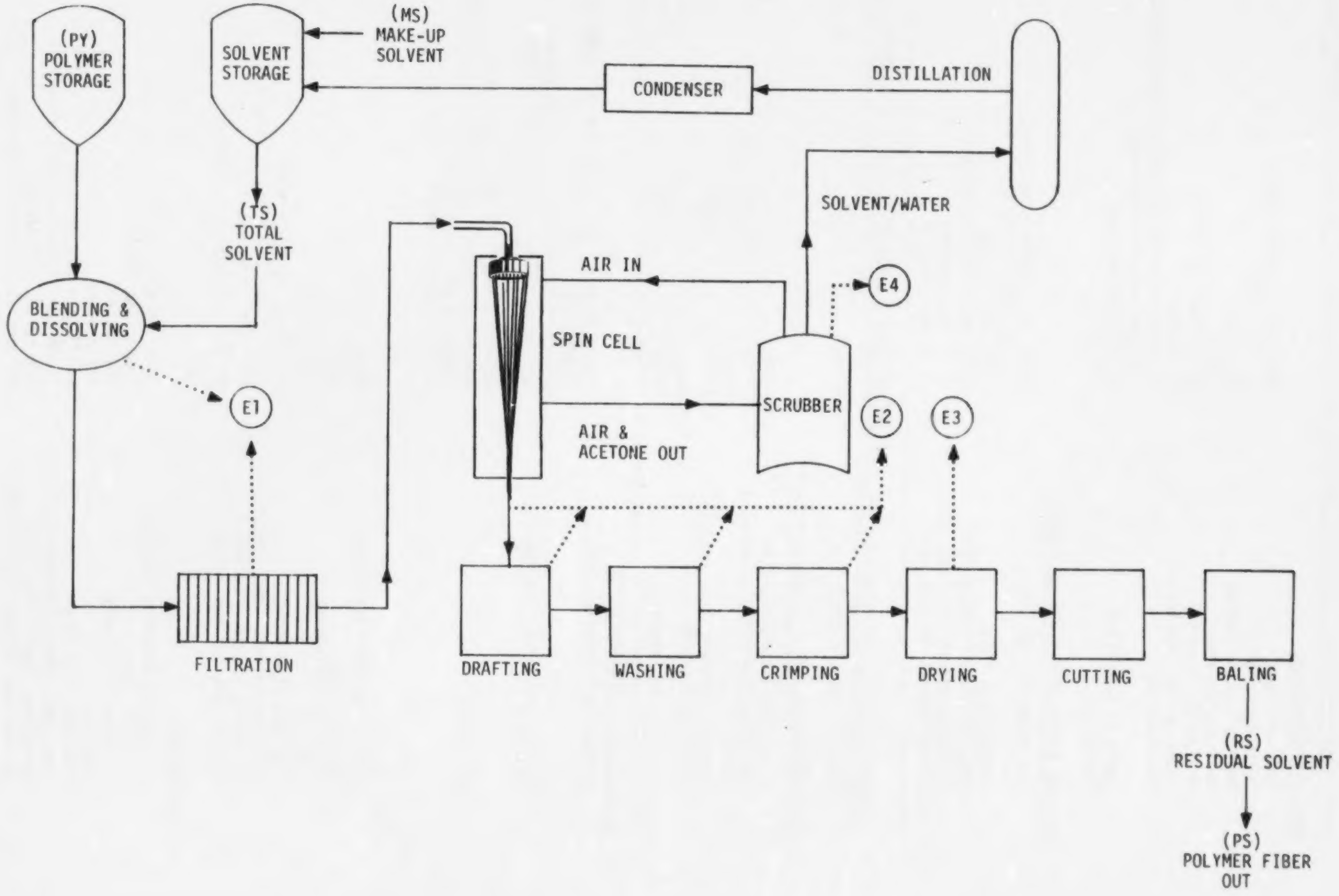
(PY)
POLYMER
STORAGE
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
CONDENSER
DISTILLATION
SOLVENT/WATER
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
AIR IN
E4
SPIN CELL
SCRUBBER
E1
E2
E3
AIR &
ACETONE OUT
FILTRATION
DRAFTING
WASHING
CRIMPING
DRYING
CUTTING
BALING
(RS)
RESIDUAL SOLVENT
(PS)
POLYMER FIBER
OUT

Figure 6-11. Modacrylic/Acrylic Dry Spinning Baseline Control, Model Plant 3

Table 6-7. PARAMETERS FOR MODEL PLANT 3

General Information	
Type of Plant	Modacrylic Fibers Plant
Spinning Process	Dry Spinning
Polymerization Medium	Suspension
Spinning Solvent	Acetone
Production Capacity	20 Gg/Year (44 MMPPY)
Capacity Utilization	95 percent
Raw Materials	Polyacrylonitrile and Vinylidene Chloride, 98 percent, 2% other material
Hours of Operation	8,400 hours per year
Pollutants	Acetone
Process Rates (Per 1,000 kg fiber)	
Raw Materials In (PY)	1,000 kg, Polymer/copolymer, 20 kg other materials
Solvent Use (TS)	2,500 kg, Acetone
Polymer Fiber Produced (PS)	1,000 kg, Modacrylic Fiber
Residual Solvent in Fiber (RS)	5 kg, Acetone
Miscellaneous Solvent Loss	10 kg, Acetone

Process Variables (Per 1,000 kg fiber)	Alternative I (Baseline)	Alternative II (Control Option A)	Alternative III (Control Option B)
Make-up Solvent (MS)	155 kg	101 kg	48 kg
Emission Sources (Per 1,000 kg fiber)			
Filtering/Dissolving (E1)	5 kg	5 kg	5 kg
Spinning/Washing/Crimping (E2)	57 kg	57 kg	3 kg
Drying (E3)	55 kg	1 kg	1 kg
Solvent Recovery Area (E4)	23 kg	23 kg	23 kg
Spinning Scrubber	-	-	1 kg
Emission Totals	140 kg	86 kg	33 kg

Exhaust Gas Characteristics	
Filtering/Dissolving (E1)	Intermittent Flow: 140 M^3/Min (5,000 ACFM) Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv
Spinning/Washing/Crimping (E2)	Continuous Flow: Fugitive Emissions Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv
Drying (E3)	Continuous Flow: 425 M^3/Min (15,000 ACFM) Temperature: 60°C (140°F) Solvent Concentration: 2,300 ppmv
Scrubber #1	
Controlled Emission Source	Dryer (E3)
Scrubber Type	Bubble cap tower
Scrubber Efficiency	98+ percent
Feed Gas	Air/Acetone
Feed Gas Flow Rate	425 M^3/min (15,000 ACFM)
Feed Gas Solvent Concentration	2,300 ppmv (2.0 kg/min), Acetone
Scrubbing Liquid Flow Rate	600 kg/hr D.M. water
Residue Gas Solvent Concentration	40 ppm (.04 kg/min), Acetone
Scrubber #2	
Controlled Emission Source	Spinning/Washing (E2)
Scrubber Type	Bubble cap tower
Scrubber Efficiency	98+ percent
Feed Gas	Air/Acetone
Feed Gas Flow Rate	425 M^3/Min (15,000 CFM)
Feed Gas Solvent Concentration	2,300 ppmv (2.0 kg/min) Acetone
Scrubbing Liquid Flow Rate	600 kg/hr, D.M. water
Residue Gas Solvent Concentration	40 ppmv (0.04 kg/min), Acetone

6.3.3.2 Regulatory Alternative II, Control Option A. The major VOC emissions from this fiber production process occur at the spinning cell fiber exit, during drawing and washing of the spun fibers, and during drying of the fiber tow. Option A for this production sequence involves the collection of the exhaust gases from the fiber dryer (which contain significant amounts of volatilized solvent) and treatment of these gases in a solvent recovery system. The solvent recovery system may consist of either a solvent scrubber or a carbon adsorption system. For the purpose of the model plant analysis, it is assumed that a scrubber is used. Assuming a solvent recovery efficiency of 98 percent, the emission reduction would amount to about 54 kg solvent per 1,000 kg of polymer processed. Capture efficiency at drying is nearly 100 percent, since 100 percent of the dryer exhausts are routed to the control device. Figure 6-12 shows the schematic diagram of this control option as applied to Model Plant 3; Table 6-7 contains the model plant parameters for this option.

6.3.3.3 Regulatory Alternative III, Control Option B. The major VOC emissions from this fiber production process occur at the spinning cell fiber exit, during drawing and washing of the spun fibers, and during drying of the fiber tow. Option B for this production sequence would require enclosure of the post spinning processing stages with the collected gases sent to a solvent recovery scrubber or carbon bed; a scrubber is specified for the model plant analysis. The exhaust gases from the fiber dryer would also be treated in a solvent recovery system. The process enclosures would be tight enough to limit the volume of gas to be treated to about 15,000 ACFM (not including dryer exhaust). At this flow rate, the VOC concentration can be maintained well below the lower explosive limit (2.6 percent by volume). Capture efficiency at post spinning processing stages would be 90 percent. Dryer emissions would be 100 percent captured. Assuming a control device efficiency of 98 percent (after capture), the VOC emission reduction from baseline control will amount to about 54 kg per 1,000 kg polymer fiber from the dryer and about 53 kg per 1,000 kg of polymer fiber from the spinning, drawing, and washing stages. Figure 6-13 shows the schematic diagram of this control option as applied to Model Plant 3; Table 6-7 contains the model plant parameters for this option.

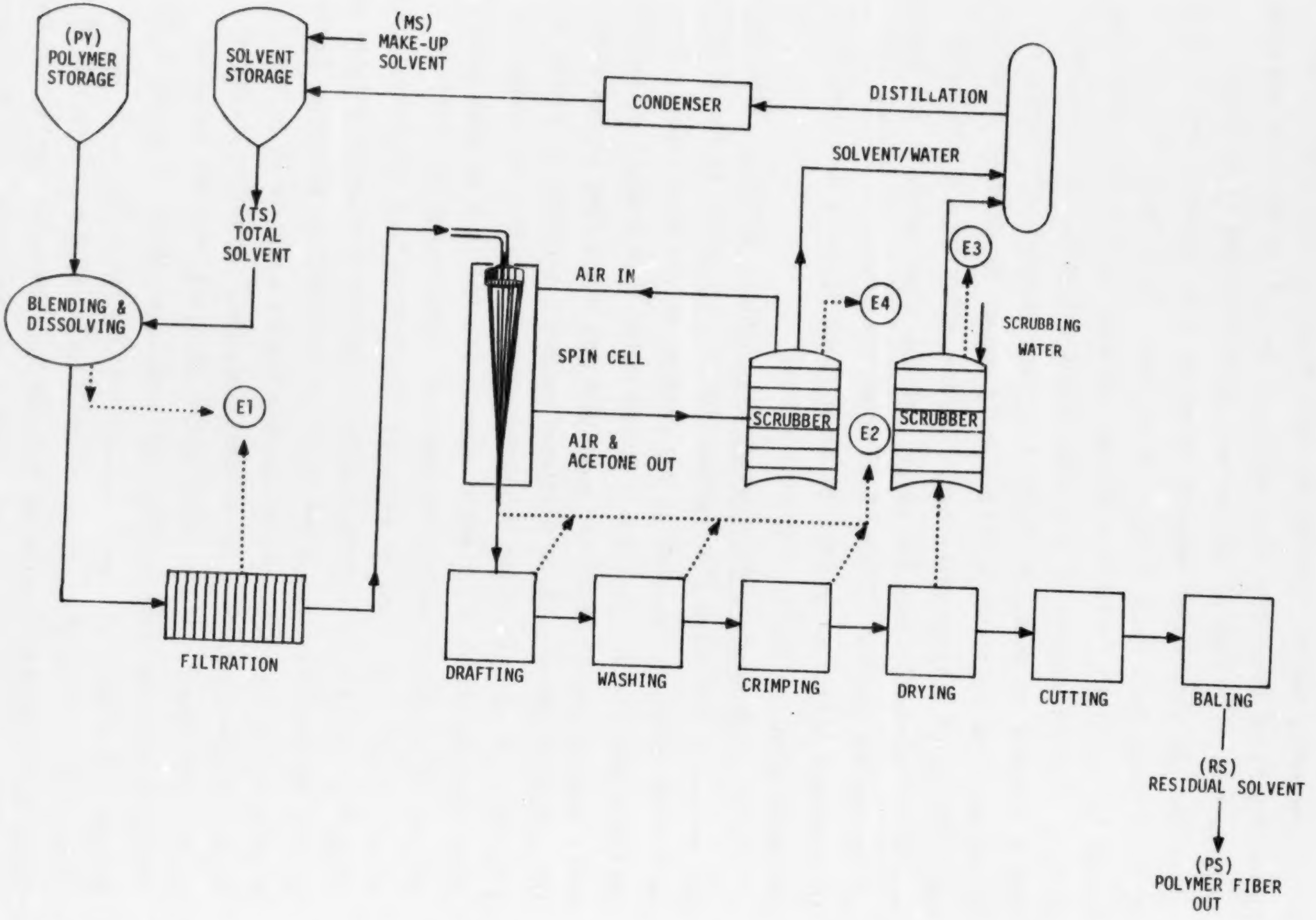
(PY)
POLYMER
STORAGE
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
CONDENSER
DISTILLATION
SOLVENT/WATER
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
E1
AIR IN
SPIN CELL
AIR &
ACETONE OUT
SCRUBBER
SCRUBBER
E2
E3
E4
SCRUBBING
WATER
FILTRATION
DRAFTING
WASHING
CRIMPING
DRYING
CUTTING
BALING
(RS)
RESIDUAL SOLVENT
(PS)
POLYMER FIBER
OUT

Figure 6-12. Regulatory Alternative II for Model Plant 3, Modacrylic/Acrylic Dry Spinning

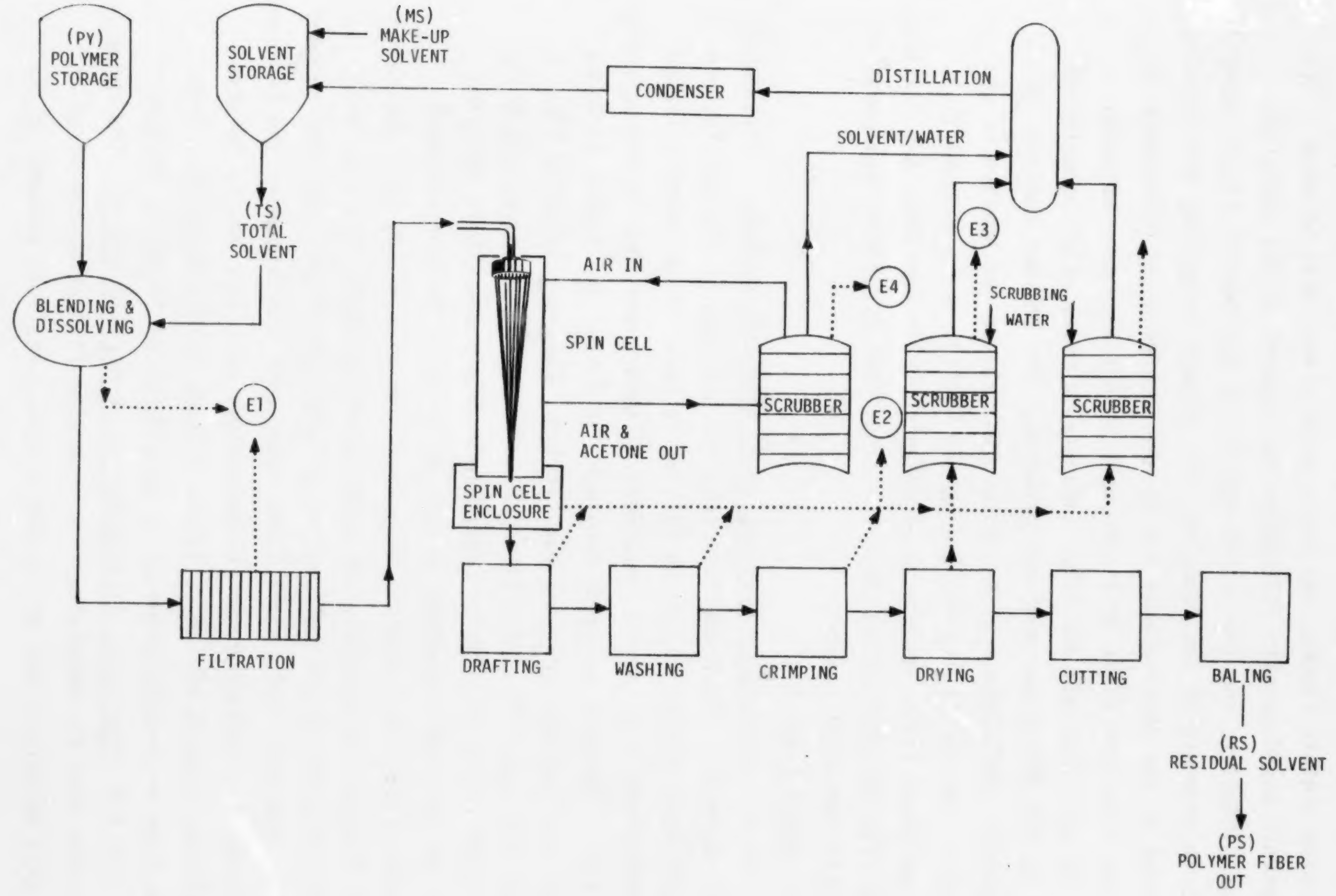
(PY)
POLYMER
STORAGE
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
CONDENSER
DISTILLATION
SOLVENT/WATER
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
E1
AIR IN
SPIN CELL
AIR &
ACETONE OUT
SPIN CELL
ENCLOSURE
E4
E3
E2
SCRUBBING
WATER
SCRUBBER
SCRUBBER
SCRUBBER
FILTRATION
DRAFTING
WASHING
CRIMPING
DRYING
CUTTING
BALING
(RS)
RESIDUAL SOLVENT
(PS)
POLYMER FIBER
OUT

Figure 6-13. Regulatory Alternative III for Model Plant 3, Modacrylic/Acrylic Dry Spinning

6.4 CELLULOSE ACETATE FIBER MODEL PLANTS AND REGULATORY ALTERNATIVES[51-68]

In order to characterize the plants utilized in production of cellulose acetate fibers, two basic model plants were selected. One represents the cigarette filtration tow segment of the cellulose acetate industry, and the second represents the textile fibers segment. For both segments of the industry, the polymer dissolving and spinning portions of the model plants are identical; the major difference in the two fiber processes is in the post spinning process segments. For the cellulose acetate fiber industry, a model plant capacity of 22.7 Gg (50 MMPPY) per year was selected. The polymer consists of 100 percent cellulose acetate; both model plants use acetone as the solvent. For a capacity of 22.7 Gg (50 MMPPY), it is assumed that four spinning lines, each with 50 spinning cells per side, are required along with the appropriate post spinning fiber processing equipment to complete the model plants.

6.4.1 Model Plant 4

6.4.1.1 Regulatory Alternative I, Baseline Control. This model plant represents the production sequence utilized in the manufacture of cellulose acetate cigarette filtration tow. Dried acetate flakes are dissolved in a solvent, blended, filtered, and sent to the spinning machines. The post spinning treatment of filter tow fibers includes finish application, crimping, and drying. The post spinning fiber processing steps are typically open to room air; the exception being the dryer which is normally controlled. Since the fibers emerging from the spin cells contain as much as 15 to 20 percent residual solvent, significant amounts of solvent are volatilized into the room air. Figure 6-14 presents the model plant schematic diagram, and Table 6-8 contains the relevant model plant parameters for this segment of the industry. This model plant represents the processes and (solvent recovery) air pollution control technology currently in use in this particular segment of the cellulose acetate fibers industry. This production or process sequence is considered as "baseline control."

6.4.1.2 Regulatory Alternative II, Control Option A. The major emissions from the manufacture of cigarette filtration tow occur in the post spinning fiber processing stages. Residual solvent in the

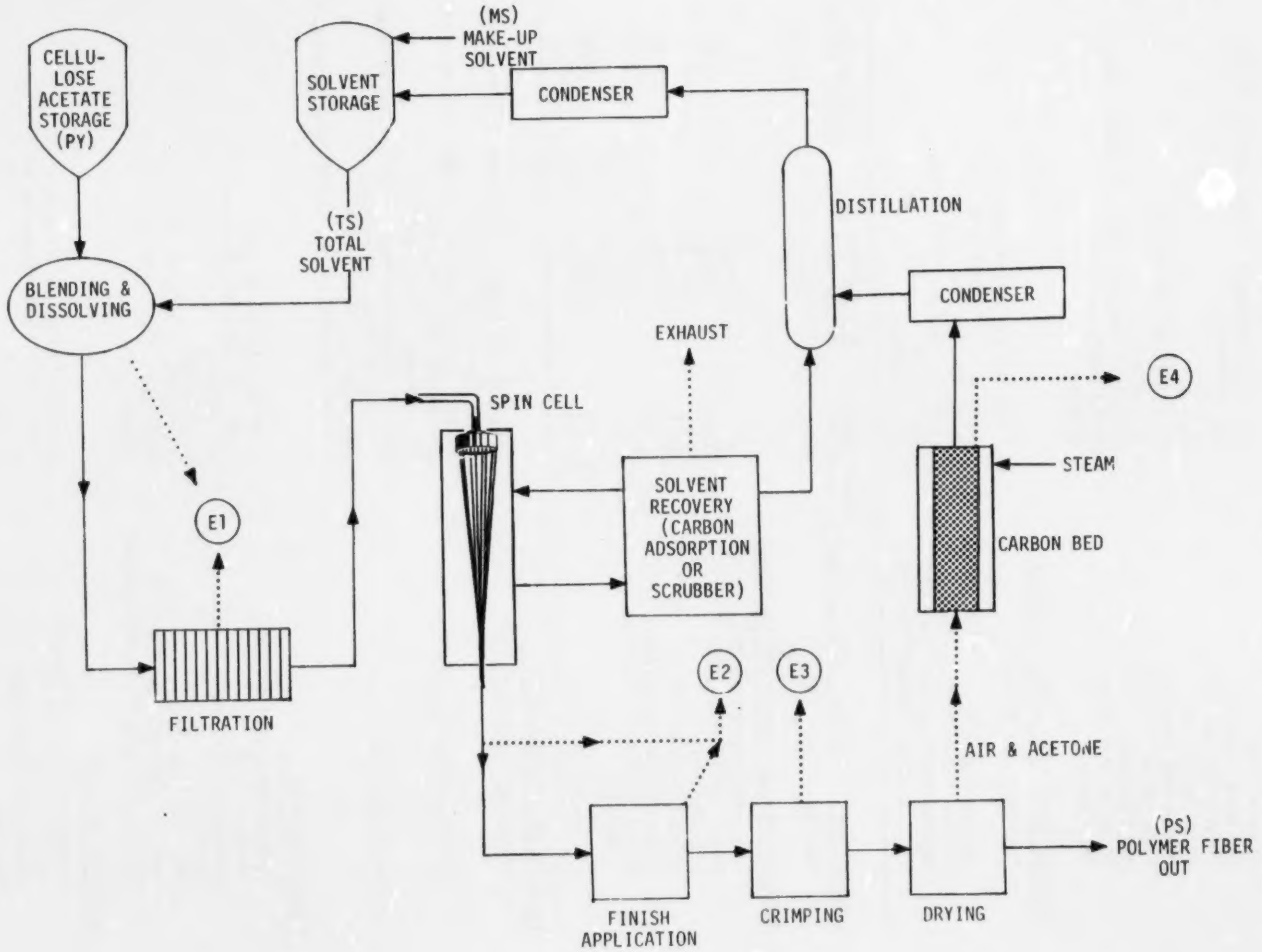
CELLU-
LOSE
ACETATE
STORAGE
(PY)
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
CONDENSER
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
DISTILLATION
CONDENSER
EXHAUST
SPIN CELL
E1
E4
STEAM
SOLVENT
RECOVERY
(CARBON
ADSORPTION
OR
SCRUBBER)
CARBON BED
FILTRATION
E2
E3
AIR & ACETONE
(PS)
POLYMER FIBER
OUT
FINISH
APPLICATION
CRIMPING
DRYING

Figure 6-14. Cellulose Acetate Filtration Tow Dry Spinning Baseline Control, Model Plant 4

Table 6-8. PARAMETERS FOR MODEL PLANT 4

General Information	
Type of Plant	Cellulose Acetate Filtration Tow Plant
Spinning Process	Dry Spinning
Polymerization Medium	Solution
Spinning Solvent	Acetone
Production Capacity	22.7 Gg/Year (50 MMPPY)
Capacity Utilization	95 percent
Raw Materials	Cellulose Acetate, 98%, 2% other material
Hours of Operation	8,400 hours per year
Pollutants	Acetone

Process Rates (Per 1,000 kg fiber)	
Raw Materials In (PY)	1,000 kg, Cellulose Acetate, 20 kg other materials
Solvent Use (TS)	3,000 kg, Acetone
Polymer Fiber Produced (PS)	1,000 kg, Acetate Filter Tow
Residual Solvent in Fiber (RS)	Negligible
Miscellaneous Solvent Loss (ML)	10 kg Acetone

Process Variables (Per 1,000 kg fiber)	Alternative I (Baseline)	Alternative II (Control Option A)	Alternative III (Control Option B)
Make-up Solvent (MS)	130 kg	77 kg	54 kg
Emission Sources (Per 1,000 kg fiber)			
Filtering/Dissolving (E1)	2 kg	2 kg	2 kg
Spinning/Finishing (E2)	60 kg	6 kg	6 kg
Crimping (E3)	25 kg	25 kg	2 kg
Solvent Recovery Area	28 kg	28 kg	28 kg
Dryer Carbon Bed Exhausts (E4)	5 kg	5 kg	5 kg
Spin Enclosure Carbon Bed Exhausts	-	1 kg	1 kg
Emission Totals	120 kg	67 kg	44 kg

Exhaust Gas Characteristics	
Filtering/Dissolving (E1)	Intermittent Flow: 140 M³/Min (5,000 ACFM) Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv in room air
Spinning/Finishing (E2)	Continuous Flow: Fugitives Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv in room air
Crimping (E3)	Continuous Flow: Fugitives Temperature: 50°C (120°F) Solvent Concentration: 1,000 ppmv in room air

Carbon Adsorber #1	
Controlled Emission Source	Spinning/Finishing (E2)
Adsorber Type	Fixed Bed w/steam regeneration
Adsorption Efficiency	98+ percent
Feed Gas	Air/Acetone
Feed Gas Flow Rate	425 M³/Min (15,000 ACFM)
Feed Gas Solvent Concentration	2,500 ppmv (2.5 kg/Min), Acetone
Residue Gas Solvent Concentration	50 ppm

Carbon Adsorber #2	
Controlled Emission Source	Spinning/Finishing/Crimping
Adsorber Type	Fixed Bed w/steam regeneration
Adsorption Efficiency	98+ percent
Feed Gas	Air/Acetone
Feed Gas Flow Rate	570 M³/Min (20,000 CFM)
Feed Gas Solvent Concentration	2,650 ppmv, (3.5 kg/min), Acetone
Residue Gas Solvent Concentration	50 ppmv

fiber is volatilized into the room or building air which is then vented to the atmosphere. Option A for this production process would require the treatment of all dryer exhaust gases for solvent recovery and the enclosure of the spin cell exits and the tow line up to the crimping stage. The captured gases containing solvent vapor would be vented directly to a solvent recovery system. The solvent recovery system may consist of either a solvent scrubber or a carbon adsorption system. For analysis of this model plant case, it is assumed that a carbon adsorption system is used to recover the solvent; carbon adsorption systems are in use at nearly all cellulose acetate fiber plants for solvent recovery.

Assuming a 90 percent capture efficiency and a 98 percent solvent recovery efficiency for the spin cell enclosures and solvent recovery system, respectively, the VOC emission reduction would be about 53 kg solvent per 1,000 kg of polymer fiber processed. Figure 6-15 provides a schematic diagram of this control option as applied to Model Plant 4. Table 6-8 lists the model plant parameters corresponding to the figure. The carbon adsorption system used to recover solvent from the spin cell enclosures involves fixed bed adsorption with steam regeneration. The system includes carbon beds, blowers, condensers, piping, valves, and instrumentation.

6.4.1.3 Regulatory Alternative III, Control Option B. Option B for the control of VOC emissions from the manufacture of cigarette filtration tow requires, in addition to the treatment of all dryer exhaust gases, the use of process enclosures for control of fugitive emissions at all the post spinning fiber processing stages where residual solvent is volatilized into room air, including the crimping stage. Enclosures can be placed at the exit of the spinning cells and along the fiber processing line, up to the fiber dryer. The collected gases are then directed to a solvent recovery system. The enclosures would be sufficient to cover the equipment, tied together with proper manifolding, and equipped with doors at the correct spacing to permit operator access. The enclosures would be tight enough to restrict the air flow to about 20,000 ACFM. If a flow of 20,000 ACFM is used, the solvent (VOC) concentration can be maintained well below the solvent

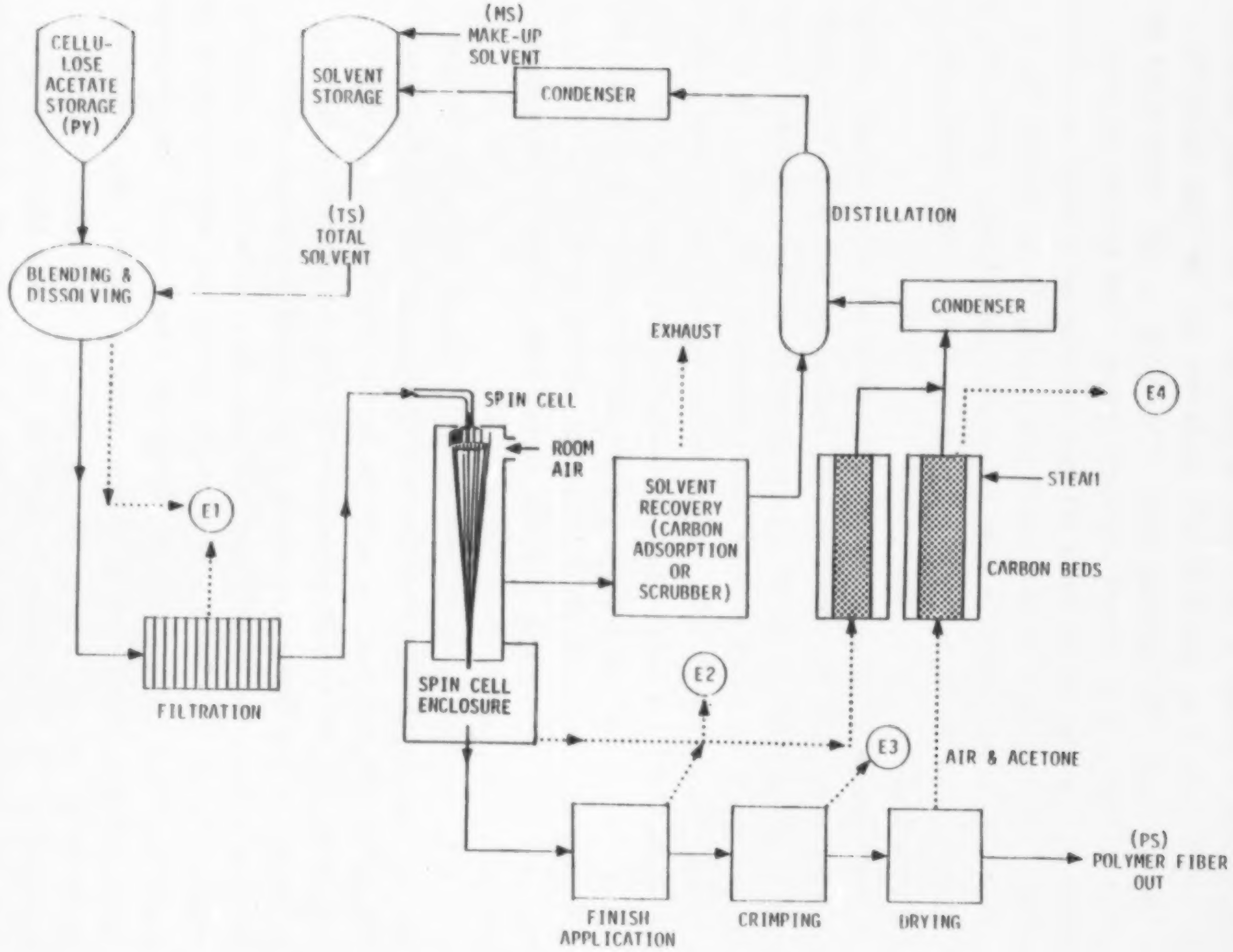
CELLU-
LOSE
ACETATE
STORAGE
(PY)
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
CONDENSER
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
DISTILLATION
CONDENSER
EXHAUST
E4
SPIN CELL
ROOM
AIR
SOLVENT
RECOVERY
(CARBON
ADSORPTION
OR
SCRUBBER)
STEAM
E1
CARBON BEDS
FILTRATION
SPIN CELL
ENCLOSURE
E2
E3
AIR & ACETONE
(PS)
POLYMER FIBER
OUT
FINISH
APPLICATION
CRIMPING
DRYING

Figure 6-15. Regulatory Alternative II for Model Plant 4, Cellulose Acetate Filter Tow

lower explosive limit (2.6 percent by volume). The solvent recovery system may consist of either a solvent scrubber or a carbon adsorption system. For the purpose of the model plant analysis, it is assumed that a carbon adsorption system is used since these solvent recovery systems are in use at nearly all cellulose acetate fiber plants.

Assuming a 90 percent capture efficiency and a 98 percent solvent recovery efficiency, the VOC emission reduction from baseline control will amount to about 76 kg of VOC per 1,000 kg of polymer processed. Figure 6-16 provides a schematic diagram of this control option as applied to Model Plant 4. Table 6-8 lists the model plant parameters corresponding to the figure. The carbon adsorption system involves fixed bed adsorption with steam regeneration. The system includes carbon beds, blowers, condensers, condensate decanter, piping, valves, and instrumentation.

6.4.2 Model Plant 5

6.4.2.1 Regulatory Alternative I, Baseline Control. The cellulose acetate textile yarn process is represented in this model plant. The process stages prior to fiber exit from the spinning cell are identical to those of acetate filtration tow. Dried acetate flakes are dissolved in a solvent, blended, filtered, and sent to the spinning machines. Immediately after spinning, acetate textile yarn is wound onto a bobbin as continuous filament yarn, with no further treatment. The yarn is later transferred to larger spools for shipment or further processing in another part of the plant. As the fibers are initially wound onto bobbins, they may still contain as much as 15 to 20 percent residual solvent. This residual solvent continuously evaporates into room or building air until equilibrium is reached in the fiber at around 1 or 2 percent (by weight) residual solvent. These fugitive emissions are about 145 kg VOC per 1,000 kg of polymer processed on an industry-wide basis. Figure 6-17 presents the model plant schematic diagram, and Table 6-9 contains the relevant model plant parameters for the production sequence considered as baseline control.

6.4.2.2 Regulatory Alternative II, Control Option A. This control alternative involves the use of a gross in-plant air management scheme to achieve optimum solvent recovery. The air management system

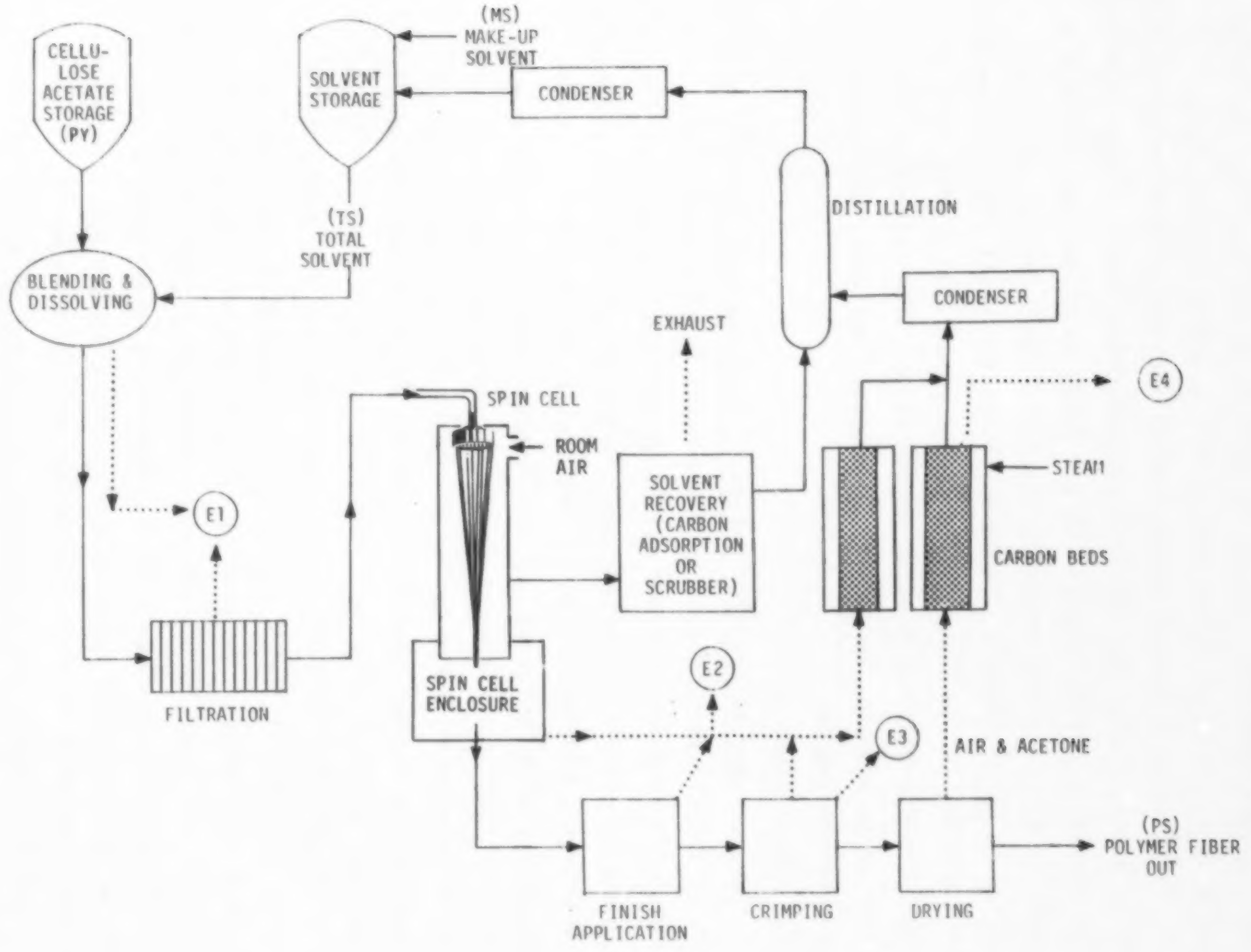
CELLU-
LOSE
ACETATE
STORAGE
(PY)
SOLVENT
STORAGE
(MS)
MAKE-UP
SOLVENT
CONDENSER
(TS)
TOTAL
SOLVENT
BLENDING &
DISSOLVING
DISTILLATION
CONDENSER
EXHAUST
SPIN CELL
ROOM
AIR
E1
E4
SOLVENT
RECOVERY
(CARBON
ADSORPTION
OR
SCRUBBER)
STEAM
CARBON BEDS
FILTRATION
SPIN CELL
ENCLOSURE
E2
E3
AIR & ACETONE
(PS)
POLYMER FIBER
OUT
FINISH
APPLICATION
CRIMPING
DRYING

Figure 6-16. Regulatory Alternative III for Model Plant 4, Cellulose Acetate Filter Tow

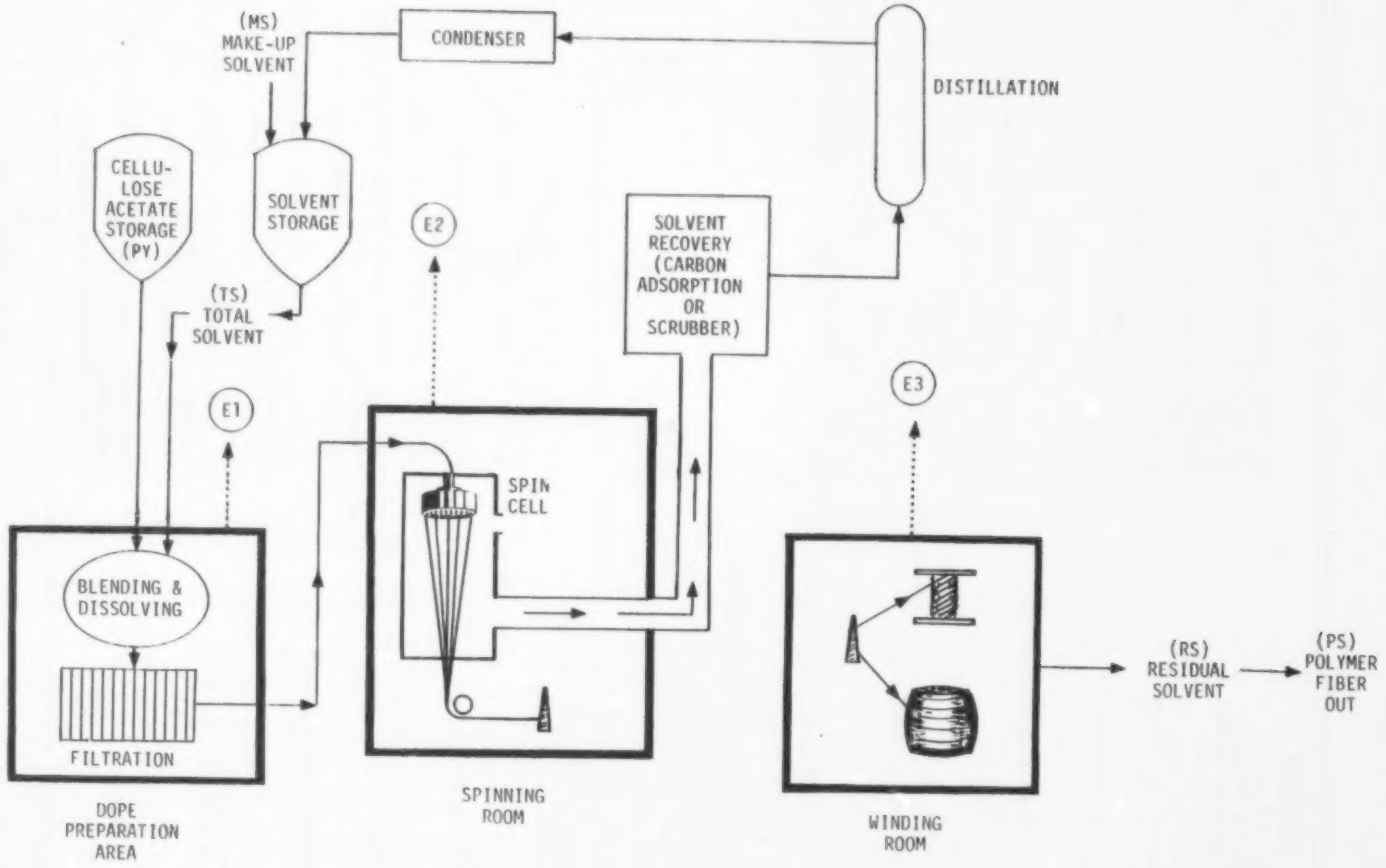
(MS)
MAKE-UP
SOLVENT
CONDENSER
DISTILLATION
CELLU-
LOSE
ACETATE
STORAGE
(PY)
SOLVENT
STORAGE
E2
SOLVENT
RECOVERY
(CARBON
ADSORPTION
OR
SCRUBBER)
(TS)
TOTAL
SOLVENT
E1
E3
SPIN
CELL
BLENDING &
DISSOLVING
FILTRATION
(RS)
RESIDUAL
SOLVENT
(PS)
POLYMER
FIBER
OUT
DOPE
PREPARATION
AREA
SPINNING
ROOM
WINDING
ROOM

Figure 6-17. Cellulose Acetate Filament Yarn Dry Spinning Baseline Control, Model Plant 5

Table 6-9. PARAMETERS FOR MODEL PLANT 5

General Information	
Type of Plant	Cellulose Acetate Textile Yarn
Spinning Process	Dry Spinning
Polymerization Medium	Solution
Spinning Solvent	Acetone
Production Capacity	22.7 Gg/Year (50 MMPPY)
Capacity Utilization	95 percent
Raw Materials	Cellulose Acetate 98 percent, 2 percent other materials
Hours of Operation	8,400 hours per year
Pollutants	Acetone

Process Rates (Per 1,000 kg fiber)	
Raw Materials In (PY)	1,000 kg, Acetate, 20 kg other materials
Solvent Use (TS)	3,000 kg, Acetone
Polymer Fiber Produced (PS)	1,000 kg, Acetate Textile Yarn
Residual Solvent in Fiber (RS)	10 kg, Acetone
Miscellaneous Non-Gaseous Solvent Loss	20 kg, Acetone
Total Solvent Evaporated to Room Air	122 kg, Acetone

Process Variables (Per 1,000 kg fiber)	Alternative I (Baseline)	Alternative II (Control Option A)	Alternative III (Control Option B)
Make-up Solvent (MS)	175 kg	96 kg	70 kg
Emission Sources (Per 1,000 kg fiber)			
Filtering/Dissolving (E1)	5 kg	1 kg	1 kg
Spinning/Winding (E2) (E3)	105 kg	30 kg	4 kg
Solvent Recovery Area	30 kg	30 kg	30 kg
Miscellaneous Fugitives	5 kg	5 kg	5 kg
Emission Totals	145 kg	66 kg	40 kg

Exhaust Gas Characteristics	
Filtering/Dissolving (E1)	Intermittent Flow: Fugitive Losses Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv
Spinning/Winding (E2) (E3)	Continuous Flow: Fugitive Losses Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv
Total Air to Extrusion Room From Filtering/Winding	Continuous Flow: 3,500 M^3/Min (125,000 ACFM) Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv
Room Air Used as Process Air in Alternatives II and III	Continuous Flow: 3,500 M^3/Min (125,000 ACFM) Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv
Room Air Lost as Fugitives (E1, E2, E3, and Misc.)	Continuous Flow: 700 M^3/Min (25,000 ACFM) Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv
Room Air Sent Directly to Recovery	Continuous Flow: 1,400 M^3/Min (50,000 ACFM) Temperature: 27°C (80°F) Solvent Concentration: 1,000 ppmv

requires the re-use of plant air from the three basic process areas of the fiber plant. Room air from the dope preparation area (dissolving, mixing, filtering) and room air from the twisting/coning/beaming areas, both of which contain low levels of solvent, are vented (transported) to the extrusion room at a predetermined flow rate. The extrusion room air can then be used to supply the process or evaporation air for the spinning-cell solvent evaporation system. The solvent-rich process air, together with a fixed amount of solvent-lean extrusion room air, is then vented directly to a solvent recovery system. The ratio of process air to (direct) room air may vary somewhat depending on the individual plant. To properly accomplish the air management program, the plants would likely maintain a slight negative room pressure of about 0.1 to 0.2 inches of water.

For a cellulose acetate textile yarn plant capacity of 22.7 Gg/year (50 MMPPY), a total of about 125,000 CFM would be sent to the solvent recovery system. Of this amount, about 125,000 CFM, nearly all the gas would be from the spinning cells; little or no air would be taken directly from the extrusion room. Figure 6-18 and Table 6-9 present the relevant model plant parameters for this option. Since this model plant represents that segment of the cellulose acetate fiber industry which produces textile filament yarn, consideration has been given to the fact that a plant of this type might utilize more than one solvent in the production of acetate fibers. Solvent-laden air streams would therefore contain two or more VOC's, and carbon adsorption efficiency of any given system will tend to be lower on a multiple organic feed versus a single organic (see Chapter 4 for discussion). To account for this, a lower overall recovery efficiency is assigned to this model plant control scheme, 95 percent as opposed to 98 percent. Assuming a 95 percent solvent recovery efficiency from the control device, the VOC emission reduction would amount to about 79 kg of VOC per 1,000 kg of polymer processed. The solvent recovery system may consist of either a solvent scrubber or a carbon adsorption system. For the purpose of the model plant analysis, it is assumed that a carbon adsorption system is used. The carbon adsorption system involves fixed bed adsorption with steam regeneration. The system includes

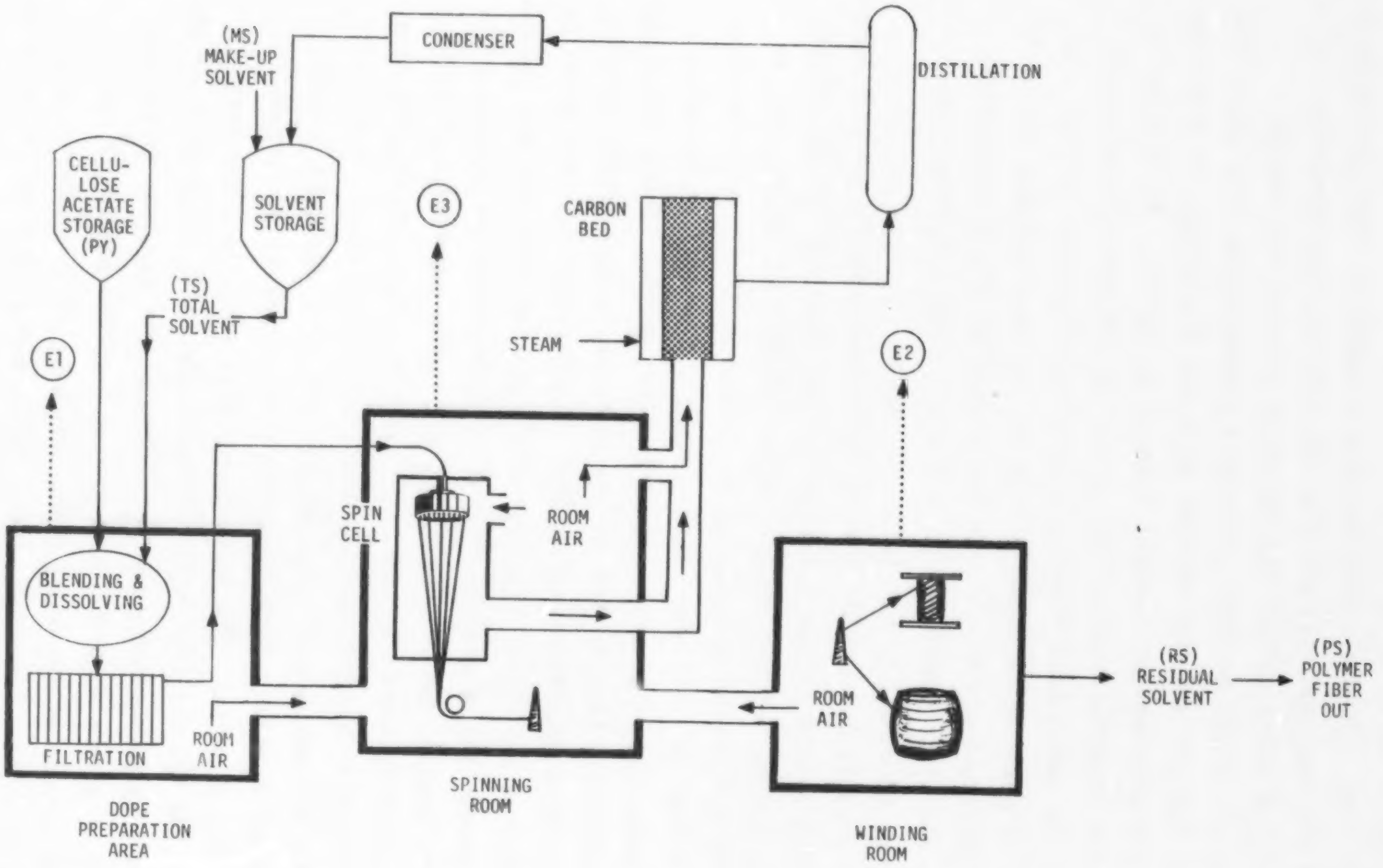
(MS)
MAKE-UP
SOLVENT
CONDENSER
DISTILLATION
CELLU-
LOSE
ACETATE
STORAGE
(PY)
SOLVENT
STORAGE
(TS)
TOTAL
SOLVENT
E3
CARBON
BED
STEAM
E1
E2
SPIN
CELL
ROOM
AIR
BLENDING &
DISSOLVING
FILTRATION
ROOM
AIR
ROOM
AIR
(RS)
RESIDUAL
SOLVENT
(PS)
POLYMER
FIBER
OUT
DOPE
PREPARATION
AREA
SPINNING
ROOM
WINDING
ROOM

Figure 6-18. Regulatory Alternatives II and III for Model Plant 5, Cellulose Acetate Filament Yarn

carbon beds, blowers, condensers, piping, valves, and instrumentation. Design parameters include operating capacity, carbon requirements, flow rates, temperatures, bed depth, pressure drop, loading time, bed area, cycle time, and regeneration requirements.

6.4.2.3 Regulatory Alternative III, Control Option B. The control alternative involves use of the same in-plant air management scheme described in Option A. The difference is that this Option calls for the treatment of an additional 50,000 ACFM of extrusion room air. A total of about 175,000 CFM would be sent to the solvent recovery system. Of this amount 125,000 CFM would be from the spinning cells, and 50,000 CFM would be taken directly from the extrusion room. Extrusion room make-up air of 50,000 CFM would be drawn from the pre-spinning and post-spinning process areas. A bypass system is necessary to ensure the room air concentration does not exceed 1,000 ppm. This control option would also require measures to adequately control the loss of extrusion room air to the atmosphere from the building door, windows, etc. A negative pressure of about 0.1 to 0.2 inches of water would likely be maintained in the buildings to prevent losses. Total solvent loss as fugitives in room air would then amount to about 13 kg of solvent per 1,000 kg of polymer. Figure 6-18 and Table 6-9 present the relevant model plant parameters for this option. Assuming a 95 percent solvent recovery efficiency from the carbon beds, the VOC emission reduction will amount to about 105 kg per 1,000 kg of polymer.

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7.0 ENVIRONMENTAL IMPACT

7.1 INTRODUCTION

Volatile organic compound (VOC) emissions occur at a multitude of sources within a synthetic fiber plant. These emissions occur both inside and outside the plant during several processes, some of which are polymer/solvent mixing and preparation, spinning, and fiber processing. Chapter 6 discusses several model plants that were used to determine VOC emissions from these various stages.

Total VOC emissions nationwide resulting from the manufacture of the synthetic fiber types being investigated in this study were estimated for 1982. This assumed fiber production at 95 percent capacity for each plant. Estimates were made of emissions in 1987, assuming the implementation of the various regulatory alternatives. Chapters 3 and 6 contain a more complete discussion of the Regulatory Alternative I (baseline) emission levels.

This chapter presents an assessment of the regulatory alternatives discussed in Chapter 6. The impacts of these alternatives associated with air, solid waste, energy consumption, and other environmental concerns will be discussed in the following sections.

7.2 AIR QUALITY IMPACT

The air pollution impact of each regulatory alternative is determined by comparison of VOC emissions from various systems installed on the appropriate process stages or points to control VOC emissions. In order to analyze the incremental air quality impact of the resulting levels of VOC emission reduction, annual VOC emission rates under each regulatory alternative were determined and then employed to project 5-year impacts on national air quality.

Table 7-1 shows, for each fiber type, the amount of fiber produced at synthetic fiber plants that would fall into one or more of the five model plant categories. Production figures for 1987 for each fiber

Table 7-1. PROJECTED 1987 VOC EMISSIONS UNDER REGULATORY ALTERNATIVES I (BASELINE), II, AND III

Fiber Type	Growth Scenario 1982-1987	1987 Number of Affected Facilities	1982 Prod, (Gg)[1]	1987 Prod, (Gg)[2]	1987 NSPS Affected Prod, (Gg)[1]	Baseline Emis. Factor[2] (kg/Mg Fiber)	Alt. II Emis. Factor[2]	Alt. III Emis. Factor[2]	Baseline Emis. Mg	Alt. II Emis. Mg	Alt. III Emis. Mg	Alt. II Emis. Reduction Mg	Alt. III Emis. Reduction Mg	Alt. II % Reduction	Alt. III % Reduction
Acrylic/ Modacrylic	High Low	2 0	372.7 364.8	444.8 395.0	73.5 --	45	31	18	3,300 --	2,280 --	1,320 --	1,020 --	1,980 --	31% --	60% --
Cellulose Acetate Filter Tow	High Low	4 2	209.4 186.3	299.7 227.8	86.3 43.1	120	67	44	10,350 5,170	5,780 2,890	3,790 1,890	4,570 2,280	6,560 3,280	44% 44%	63% 63%
Cellulose Acetate Textile Yarn	High Low	0 0	145.8 145.9	153.2 152.9	-- --	145	66	40	-- --	-- --	-- --	-- --	-- --	-- --	-- --
Spandex (Dry-Spun)	High Low	1 0	5.5 5.5	8.0 6.0	2.5 --	12	12	12	30 --	30 --	30 --	-- --	-- --	-- --	-- --
Totals	High Low	7 2	--	--	--	--	--	--	13,680 5,170	8,060 2,890	5,110 1,890	5,590 2,280	8,540 3,280	41% 44%	62% 63%

[1] These values are derived in Chapter 9, Economic Analysis.

[2] Emission factors are explained in Chapter 6, Model Plants and Regulatory Alternatives.

type were derived by projecting the highest and lowest expected growth rates as determined in the economic analysis (Chapter 9). The table also projects the 1987 emissions and emission reductions resulting from the implementation of each regulatory alternative. For the purposes of this analysis, it is assumed that minor production increases achieved through debottlenecking will not result in emission increases, and would therefore not subject the facility to a new source standard.

7.2.1 Wet and Dry-Spun Acrylic and Modacrylic Fibers

Existing acrylic fiber production facilities were assumed to be operating at essentially full capacity in 1982. The projected capacity shortfall in 1987 is expected to be 73.6 Gg, in a high-growth scenario, and zero Gg in a low-growth scenario. In order to meet the expected demand under the high-growth scenario, two new facilities will be required. Each facility will have an annual capacity of 45.4 Gg (100 million pounds) (see Chapter 6). However, it is expected that the facilities will only be operating at 81 percent capacity. Assuming new plants are needed, the production increase in 1987 will amount to a 20 percent cumulative increase over 1982 production. (See Chapter 9 for further discussion of projected growth.)

There will be a corresponding increase in VOC emissions resulting from this production increase. Under Regulatory Alternative I (baseline) conditions, the expected emissions increase from facilities potentially subject to the NSPS would be zero to 3,300 Mg/year, under the low- and high-growth scenarios, respectively.

If Regulatory Alternative II were implemented at these same facilities, the annual emissions would be zero to 2,280 Mg, depending on the growth rate. The emission reduction resulting from the implementation of this alternative would be zero to 1,020 Mg/year.

If Regulatory Alternative III were implemented at these facilities, the annual emissions would be zero to 1,320 Mg, depending on the growth rate. The emission reduction resulting from the implementation of this alternative would be zero to 1,980 Mg/year.

Since demand for acrylic fibers can be met substantially with production from either wet or dry spinning processes, the two have been combined for the purpose of estimating the environmental impact of increased production. As well, the impact of any new modacrylic fiber production is considered along with acrylic production.

7.2.2 Cellulose Acetate Cigarette Filtration Tow

Existing cellulose acetate filtration tow manufacturing facilities were assumed to be operating at essentially full capacity in 1982. The projected capacity shortfall in 1987 is expected to be 43.7 Gg under a low-growth scenario and 95.1 Gg under a high-growth scenario. In order to meet the expected demand, two new facilities will be required under the low-growth scenario, and four new facilities under the high-growth scenario. (Each facility, as described in Chapter 6, has an annual capacity of 22.7 Gg (50 million pounds).) These facilities are expected to operate at 95 percent capacity. The increase in production from 1982 to 1987 is projected to be 43.1 Gg/year under the low-growth scenario, and 86.3 Gg/year under the high-growth scenario. This amounts to a 22 to 43 percent increase over the period. (See Chapter 9.)

There will be a corresponding increase in VOC emissions resulting from this production increase. Under Regulatory Alternative I (baseline) conditions, the expected emissions increase from facilities potentially subject to the NSPS would be 5,170 to 10,350 Mg/year, under the low- and high-growth scenarios, respectively.

If Regulatory Alternative II were implemented at these same facilities, the annual emissions would be 2,890 to 5,780 Mg, depending on the growth rate. The annual emission reduction resulting from implementation of this alternative would be 2,280 to 4,570 Mg.

If Regulatory Alternative III were implemented at these facilities, the annual emissions would be 1,890 to 3,790 Mg, for the low- and high-growth scenarios, respectively. The emission reduction resulting from the implementation of this alternative would be 3,280 to 6,560 Gg/year.

7.2.3 Cellulose Acetate Textile Yarn

It is assumed that all increases in demand for cellulose acetate textile yarn between 1982 and 1987 will be met either through debottlenecking or through increases in capacity utilization of equipment already in place in 1982. (See Chapter 9 for an explanation of the projections for this fiber type.) It is further assumed for the purpose of this analysis that these modest increases in production will not result in emission increases, and would therefore not be subject to an NSPS. (See Chapter 5 for further discussion of the facilities potentially affected as a result of such modifications.)

Therefore, for the purpose of this analysis and projection of environmental impact, there will be no emission reduction at acetate textile yarn manufacturing plants between 1982 and 1987 resulting from implementation of Regulatory Alternatives II or III.

7.2.4 Dry-Spun Spandex Fibers

By 1987, it is expected that an additional 0.5 to 2.5 Gg of spandex will be produced annually. Additional capacity at up to one new typical-size facility (potentially subject to an NSPS) will be required to meet the expected demand. Baseline emissions from facilities of this type are already lower than the levels that would be required under either Regulatory Alternative II or III. Therefore, no model plant or control options were developed to analyze the production of this type fiber and the cost and effects of additional control equipment. Assuming the emission levels at existing facilities are duplicated at the new facilities, the expected emission increase in 1987 can be estimated. Under the low-growth scenario, there would be essentially no emission increase. Under the high-growth scenario, the emissions increase would be 30 Mg annually. There would be no emission reduction directly attributable to the implementation of the NSPS, since there would be no regulatory impact except to ensure that any new facilities perform at least as well as existing facilities.

7.2.5 Other Solvent-Spun Fibers

For the reasons given in Section 6.1, model plants and regulatory alternatives were not devised for analysis of hypothetical new plants producing all possible fiber types. However, it is possible that there will be an increase in production of several fiber types for which no model plants were developed. There would also be a corresponding emission increase resulting from this new production. However, the total of all these emission increases is expected to be substantially lower than the increases from new production of the commodity fibers. Therefore, for the purpose of evaluating the environmental impact of the regulatory alternatives, no emission reduction attributable to the alternatives is considered for other solvent-spun fibers than those specifically mentioned.

7.2.6 Total VOC Emission Reduction

Most VOC emissions from synthetic fiber manufacturing facilities are generated at solvent-spun fiber production facilities, as explained in earlier sections. Baseline emissions in 1980 from these facilities are given in Table 3-9, in Chapter 3. These are the types of facilities that would potentially be subject to an NSPS. Applying the appropriate growth rates for affected fiber types and spinning methods, Regulatory Alternative I emissions would increase by 5,170 to 13,680 megagrams during the 1982-1987 period, depending on the collective industry growth rate.

Under Regulatory Alternative II, a decrease in VOC emissions of 2,280 to 5,590 megagrams would be realized over the corresponding baseline emissions under Regulatory Alternative I in 1987. This would amount to a reduction of 41 to 44 percent. VOC emissions from the manufacture of affected solvent-spun synthetic fibers in 1987 under Regulatory Alternative II controls would be 2,890 to 8,060 megagrams.

Regulatory Alternative III controls placed on the manufacture of affected synthetic fibers would reduce VOC emissions from affected facilities within the synthetic fibers industry 3,280 to 8,540 megagrams. This would be a reduction of 62 to 63 percent from baseline emissions. VOC emissions released from affected synthetic fiber manufacturing plants in 1987 under Regulatory Alternative III controls would be 1,890 to 5,110 megagrams.

Emission reductions could be significantly greater than the amounts indicated in this chapter. If new fiber manufacturing equipment were installed at existing facilities, and the additions resulted in overall emission increases, then the entire affected facility would potentially be subject to the NSPS. (See Chapter 5, Modification and Reconstruction for further discussion of applicability.) If the existing facility were formerly generating VOC emissions at levels greater than allowed under the NSPS, but were to retrofit sufficiently to achieve NSPS-allowed levels, then an emission reduction would be achieved that is not specifically forecast in this chapter.

7.2.7 Secondary Air Pollution Impact

Secondary air pollutants are those emissions which are not usually associated with a baseline controlled facility, but which result from the use of pollution control equipment required under Regulatory Alternatives II or III. VOC emission control devices and techniques which may be incorporated include, at a minimum, those discussed in Chapter 4.

Secondary air pollution problems due to the use of carbon adsorption are expected to be minimal. Gases may be emitted if the VOC stream contacts the carbon bed before it is adequately cooled following desorption. Proper cooling procedures following regeneration should reduce thermal decomposition of VOC's.

Secondary air pollutants from scrubbers are not expected to be significant, especially when compared to the contribution of pollutants from other operations in a plant. The exhaust stream is typically 1 to 2 percent of the inlet vapor concentration. While incinceration would result in reductions in the emissions of solvent vapor, there would be significant secondary air pollution impacts, resulting from the formation of oxides of nitrogen, oxides of sulfur, and carbon monoxide. However, since recovery of solvents is essential to economical operation, incineration is not expected to be a viable technique for this industry.

7.3 WATER QUALITY IMPACT[1-7]

7.3.1 Model Plants Utilizing Scrubbers as Control Devices

Adverse environmental effects resulting from the operation of a scrubber (absorber) could include improper disposal of the organic-laden liquid effluent, undesired emissions from the scrubber stack resulting from interaction within the scrubber, loss of absorbent to the atmosphere, and increased water usage. However, add-on water scrubbing systems usually mean only minimal increases in the existing water treatment facilities at a plant.

Water used in scrubbing the solvent vapor from the gas stream is piped to distillation columns where 98 to 99+ percent of the solvent is separated from the water. The exact amount would depend on temperature, solvent/water ratio, and the azeotrope formed by the solvent and water. The water stream leaving the column is normally routed back to the process; thus any solvent remaining in the water would be reintroduced to the process.

Water streams may also be directed to plant-operated waste treatment facilities for disposal. The concentration of solvent in the waste stream from the scrubber is very low, since maximum recovery of solvents is necessary. Therefore, the actual solvent loading in the waste stream sent to a waste treatment plant is expected to be minimal.

7.3.2 Plants Utilizing Aqueous Salt Spinning Process in Acrylic Fiber Manufacturing

Of the various processes used in acrylic fiber production, the aqueous salt spinning processes generate the least VOC emissions. This is the case since no organic solvent is introduced into the process, and no VOC is volatilized during any of the spinning or processing stages.

However, the use of a salt (zinc chloride or sodium thiocyanate, for example) in aqueous solution creates potential water pollution problems which must be alleviated in a wastewater treatment plant at the manufacturing facility prior to ultimate disposal. Since this study addresses major VOC emission points and this type process has no major solvent VOC emission points, then the aqueous salt spinning process is excluded from consideration. There will, therefore, be no increased water pollution impact at plants utilizing this process as a result of the implementation of the NSPS.

7.4 SOLID WASTE IMPACT[1,4-8]

7.4.1 Plants Utilizing Distillation Columns as an Integral Part of the Solvent Recovery System

A very minimal amount of organic material will accumulate and form "still bottoms," usually a heavy, tar-like compound, after extended column operation. This material is typically removed during column cleanout and landfilled. The amount of increase would be relative to the increase in solvent recovered. Relative to the total amount of solvent distilled and to the amount of "still bottoms" generated, the increase due to the application of Regulatory Alternative II or III would be negligible and not measurable.

7.4.2 Filtration Media Disposal

Since the use of filter media is proportional to the amount of polymer/solvent mixture filtered (and sent to spinning), any increase in solvent recovery as a result of this NSPS would have no effect on filtration media use. An increase or decrease in production rate, however, would directly affect the quantity of filter media used and disposed.

7.4.3 Plants Utilizing Carbon Adsorption[9]

Carbon adsorption is proposed as one of the alternative control techniques in several of the model plants noted in Chapter 6. The carbon in use is typically washed annually, and from 5 to 15 percent (10 percent on the average) of the carbon is lost as fines at each washing.

Although the increased requirement of carbon for collection of incremental increases of solvent (due to the control alternatives) should theoretically be proportional to the increased solvent controlled, this study assumes no excess capacity exists at any given carbon adsorption control device. Therefore, the smallest increase in capacity of carbon adsorption is that of one totally new unit, consisting of three adsorption beds (one in use, one cooling, and one desorbing).

Using existing units as models, the average bed contains approximately 25,000 pounds (11,300 kilograms) of carbon at 30 pounds/square foot (480 kg/m^3). A 3-bed unit will contain approximately 75,000 pounds (34,000 kg) carbon, 10 percent of which will be lost (waste) annually.

Thus, the additional carbon waste generated as a result of Regulatory Alternative II or III will be approximately 3,400 kg (7,500 pounds) annually for each affected facility, or as much as 27,000 kg (60,000 pounds) total for all such facilities.

7.4.4 Miscellaneous Waste Streams

Waste polymer and inorganic compounds from the polymer preparation area are carried by the wastewater stream to the liquid waste system. Waste polymer and inorganic compounds collected in the solvent recovery system are usually processed to reduce solvent content. The resulting solids are then mixed with water and pumped to the liquid waste system.

Spun waste from the spinning area is washed to remove solvent and is buried in a sanitary landfill, or redissolved in the appropriate solvent and reintroduced into the process at the polymer/solvent mixing area.

The main waste streams are from the polymer preparation area, the solvent recovery area, and the domestic sewage. These streams are reduced to sludge by standard wastewater treatment. Approximately 2,400 pounds per day are generated at a plant producing 100 million pounds of fiber product per year. No measurable increase in the amount of any sludge is expected from application of the proposed control alternatives.

7.5 ENERGY IMPACT[5,6,8,10]

The fiber manufacturing industry is energy intensive, with substantial amounts of electricity, coal, oil, and natural gas being consumed. For example, a typical fiber plant producing 100 million pounds of fiber annually will consume from 15 to 30 million kWh of electricity, 120 to 150 million tons of coal, 7,500 to 8,000 million cubic feet of natural gas, and 400 to 600 thousand gallons of oil. (These figures are for entire plants, however, and not only the affected facilities.)

With reference to solvent recovery, energy is required to supply steam for carbon bed regeneration. The amount of steam required is approximately 3 pounds of steam per pound of organic vapor adsorbed. Energy in the form of a cooling water system is used to cool the gas streams to optimum adsorption temperatures. Electrical energy is required to move the large volumes of air utilized in the process. Also, blowers are required to overcome the pressure drop encountered by the gas moving through the adsorption bed. A balance must be reached between the adsorption efficiency prescribed by the density and thickness of the bed and the increased electrical requirement to overcome the increased pressure drop.

The two regulatory alternatives above baseline control have assumed grass roots installation of control devices will be required. No existing excess capacity of control devices will be utilized in the control analysis. Thus, the additional solvent recovered in the various options is calculated to require new control devices, and the minimum additional energy requirement is that for operation of a new scrubber or adsorption unit and the associated distillation columns.

Typical energy requirements of an adsorption system are indicated in Figure 7-1; an adsorber with an inlet flow rate of 20,000 scfm and 25 percent LEL will require 2.75 million BTU/hour (total energy requirement). A scrubber operating at similar flow rates will require approximately 300,000 BTU/hour total energy input (see Figure 7-2).

For typical plants in the synthetic fibers industry, an increase in energy consumption would result from compliance with either Alternative II or III. The increase will also depend on the growth rate of a given fiber type. The incremental energy increase required to operate the additional control equipment for each plant type under Regulatory Alternatives II and III are shown in Table 7-2. Energy requirements required under Regulatory Alternatives II and III in 1987 under a low-growth scenario would be 42 and 88 terajoules (39 and 83 billion Btu) per year, respectively. Energy requirements for increased control at all affected facilities in 1987 under Alternatives II and III would be 224 and 430 terajoules (210 and 403 billion Btu) per year, respectively, in 1987 under the high-growth scenario. These overall energy increases would amount to less than 3 percent of the total energy (2,700 terajoules or 2,500 billion Btu) required to operate all equipment at a typical synthetic fiber manufacturing plant (not just the incremental control equipment).

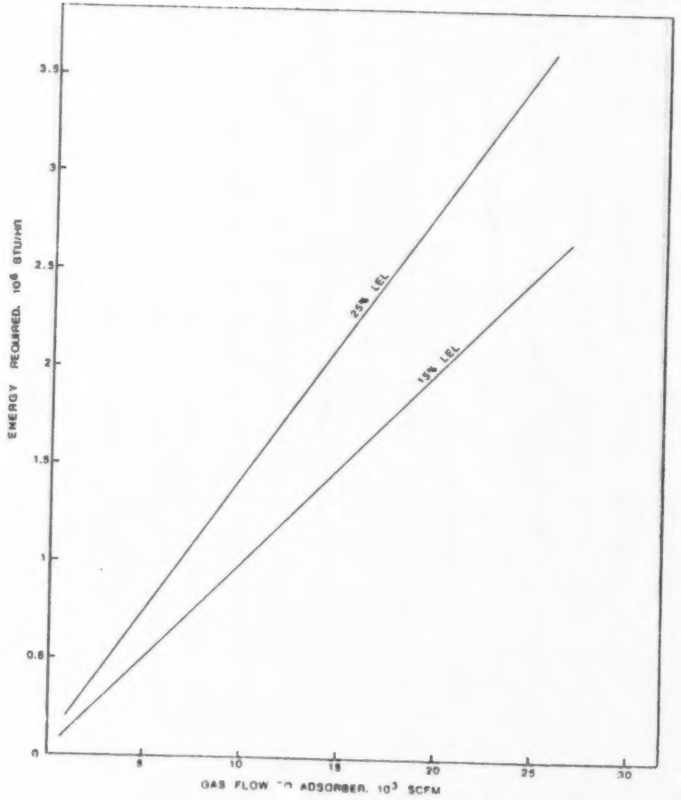
7.6 OTHER ENVIRONMENTAL IMPACTS

No other adverse environmental impacts are expected to arise from the implementation of standards of performance for synthetic fiber manufacturing, regardless of the regulatory alternative selected as the basis for standards.

7.7 OTHER ENVIRONMENTAL CONCERNS

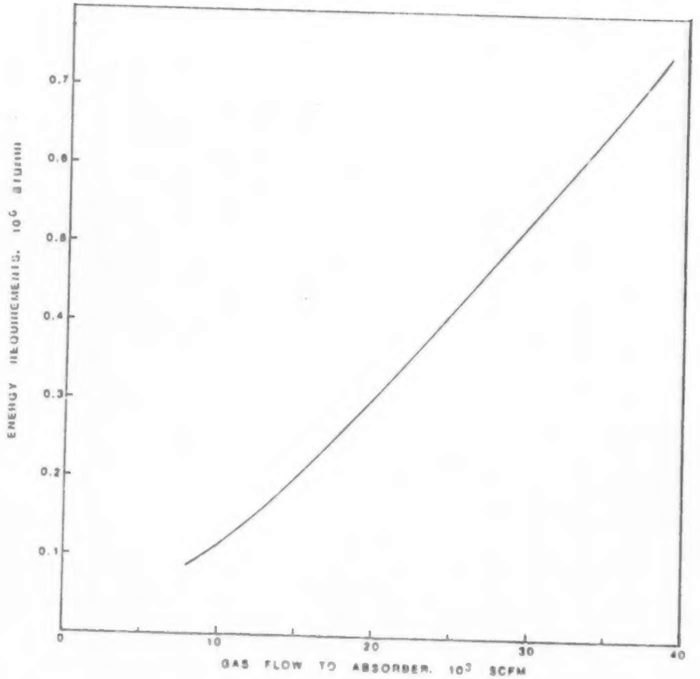
7.7.1 Irreversible and Irretrievable Commitment of Resources

The alternative control systems will require installation of additional equipment in new sources for each alternative emission control system. This requirement will necessitate the additional use of steel and other resources. The commitment of resources will be small compared to national use of each resource. Ultimately, a large quantity of these resources may be salvaged and recycled. No significant



Energy Requirement for Adsorption-Solvent Recovery System

Figure 7-1



Energy Requirements for a Typical Cross-flow Packed Scrubber Operation

Figure 7-2

Table 7-2. ENERGY IMPACT[a] OF REGULATORY ALTERNATIVES IN 1987

LOW-GROWTH SCENARIO

Fiber Type	Regulatory Alternative II[b]	Regulatory Alternative III[b]
Acrylic/ Modacrylic	0 terajoules	0 terajoules
Acetate Filter Tow	42 (21)[3]	88 (44)[3]
Acetate Filament Yarn	0	0
Total	42 terajoules	88 terajoules

HIGH-GROWTH SCENARIO

Fiber Type	Regulatory Alternative II[b]	Regulatory Alternative III[b]
Acrylic/ Modacrylic	140 (70)[c] terajoules	254 (127)[c] terajoules
Acetate Filter Tow	84 (21)[c]	176 (44)[c]
Acetate Filament Yarn	0	0
Total	224 terajoules	430 terajoules

[a] These values reflect the energy impact of the expected number of affected facilities in operation in 1987.

[b] These energy impacts are the incremental energy required to operate additional control equipment required by the alternatives.

[c] The numbers in parentheses represent the impact of a single affected facility.

amounts of space (or land) are required to install control equipment because all control systems can be located within little additional space. Therefore, negligible land commitment is expected for additional control devices.

7.7.2 Environmental Impact of Delayed Standards

Delay of standards proposal for the synthetic fiber manufacturing industry will have minor negative environmental effects on water and solid waste. However, delay in implementation of standards will generate additional VOC emissions at the significant rates described earlier in this chapter.

No emerying emission control technology appears imminent that could achieve greater emission reductions or result in lower costs than those represented by the emission control alternatives considered here. Consequently, delaying standards to allow further technical developments appears to present no tradeoff of higher solvent emissions in the near future for lower emissions in the longer term.

7.7.3 Environmental Impact of No Standards

Growth projections are presented in Chapter 9. The increase in production of organic solvent spun fibers will cause or contribute significantly to nationwide VOC emissions, should no additional control be imposed. The administrator has found that this may reasonably be anticipated to endanger public health or welfare.

Essentially no adverse water and solid waste impacts are associated with the alternative emission control systems proposed in this section. Therefore, as in the case of delayed standards, there is no tradeoff of potentially adverse impacts in these areas against the negative result on air quality that would result from nonimplementation of additional control.

7.8 REFERENCES

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8.0 COST ANALYSIS

8.1 SYNTHETIC FIBERS COST ANALYSIS OF REGULATORY ALTERNATIVES

8.1.1 Introduction

The following sections present estimates of the capital and annual costs for each model plant and regulatory alternative described in Chapter 6.0. These cost estimates are used to ascertain the economic impact of the regulatory alternatives upon the solvent spun synthetic fibers industry in Chapter 9.0. To ensure a common cost basis, *Chemical Engineering* cost indices were used to adjust both process and control equipment to mid-1980 dollars.

This chapter also includes estimates of the cost effectiveness of each alternative. Cost effectiveness is typically estimated by comparing the total annualized control cost to the annual reduction of emissions achieved. The various control alternatives are ranked based on their relative cost effectiveness in Section 8.4.

8.1.2 Model Plants/Regulatory Alternatives

As explained in Chapter 6, the five model plants were developed to be representative of the portion of the synthetic fibers industry which includes wet and dry solvent spinning of the fiber. The models describe two fiber types, acrylic and cellulose acetate. All fiber types considered are solvent spun; wet spun acrylic fibers employ dimethylacetamide; dry spun acrylics use dimethylformamide; dry spun modacrylic, cellulose acetate filament, and cigarette tow all employ acetone as a spinning solvent.

8.2 NEW FACILITY COSTS

8.2.1 Baseline Model Plant Costs

The baseline model plants were developed to be representative of basic organic solvent-spun manufacturing processes that in EPA's judgment are most likely to be constructed in the absence of additional regulatory action. Baseline capital costs include the costs for tank farms, chemical receiving and storage, dope preparation equipment, spinning equipment, fiber processing equipment, solvent recovery equipment, manufacturing buildings, warehouse, quality control laboratory, and other ancillary manufacturing facilities and equipment. Not included in baseline capital costs are utility generation, waste treatment, streets, parking, land purchase, and general support facilities (cafeteria, medical facilities, administrative offices). The baseline annual costs are the costs of operating and maintaining the facility. These include direct costs such as operating labor, maintenance labor and equipment, utilities, and laboratory charges; fixed charges of local taxes and insurance; and other general expenses such as plant overhead, administration, and research. These costs do not include a depreciation factor.

The purpose for estimating the baseline costs of the five model plants in question is to demonstrate the difference in annualized capital and operating costs among the various spinning techniques. Table 8-1 presents these costs along with the capital costs associated with the baseline solvent recovery systems, which capture solvent only from the spin cells, cabinets, or baths.

8.2.2 Costs of Regulatory Alternatives

This section summarizes the assumptions used in developing the control costs for the model plants and various control options. The technical operating parameters are presented in Chapter 6 and are not repeated here. Table 8-2 presents capital and annual operating costs associated with Regulatory Alternatives II and III. Table 8-3 compares capital and annual operating costs under Alternatives II and III that additional emission control systems would add to the baseline costs. Under Alternative II the additional costs of recovery equipment would add 2.9 to 9.8 percent to the baseline capital costs and an additional 1.1 to 4.5 percent to baseline annual operating costs, depending on the model plant in question. Under Alternative III capital costs would increase by 6.3 percent to 12.4 percent; annual operating costs would increase by 1.9 to 6.3 percent, depending on the model plant in question.

TABLE 8-1. BASELINE COSTS
(Millions of dollars)

Model Plant	1	2	3	4	5
Capital Costs For Process Equipment	53.2	47.6	38.1	57.1	73.6
Capital Costs For Solvent Recovery Equipment	19.0	21.9	7.0	10.0	10.0
Annual Operating Costs	51.6	46.3	23.1	25.7	27.1

NOTES: 1. Above figures are for the defined affected facility: polymer mixing with solvent for spinning, solution blending, through filtering, spinning, processing, and preparation for shipment.

2. Annual costs do not include raw materials processed, i.e., polymer, finish, and solvent.

3. Costs for Model Plants 4 and 5 include costs for equipment not a part of the affected facility, such as polymer preparation. These costs are not included in model plant costs shown for 1, 2, and 3.

4. All costs are expressed in 1980 dollars.

TABLE 8-2. CAPITAL AND ANNUAL OPERATING COSTS ASSOCIATED WITH MODEL PLANT OPTIONS
(Millions of dollars)

Model Plant	1	2	3	4	5
Regulatory Alternative I (Baseline)					
Capital Costs	72.2	69.5	45.1	67.1	83.6
Annual Operating Costs	51.6	46.3	23.1	25.7	27.1
Regulatory Alternative II					
Capital Costs	76.0	72.5	46.4	70.1	91.8
Annual Operating Costs	52.2	46.8	23.4	26.4	28.5
Regulatory Alternative III					
Capital Costs	78.7	75.0	48.1	71.3	94.0
Annual Operating Costs	52.6	47.2	23.7	26.6	28.8

NOTES:
1. Figures above for annual costs do not include recovery credits for solvent, or capital recovery costs.
2. Costs are presented for entire affected facility, with incremental additional costs included in figures for Regulatory Alternatives II and III.
3. Annual costs do not include raw materials processed, i.e., polymer, finish, and solvent.

TABLE 8-3. INCREASES IN CAPITAL AND ANNUAL OPERATING COSTS ASSOCIATED WITH EACH REGULATORY ALTERNATIVE

Model Plant Number	Type of Cost	Regulatory Alternative II		Regulatory Alternative III	
		Cost of Control* (millions of dollars)	Percent of baseline	Cost of Control* (millions of dollars)	Percent of baseline
1	Capital	3.8	5.3	6.5	9.0
	Annual Operating	0.6	1.2	1.0	1.9
2	Capital	3.0	4.3	5.5	7.9
	Annual Operating	0.5	1.1	0.9	1.9
3	Capital	1.3	2.9	3.0	6.7
	Annual Operating	0.3	1.3	0.6	2.6
4	Capital	3.0	4.5	4.2	6.3
	Annual Operating	0.7	2.7	0.9	3.5
5	Capital	8.2	9.8	10.4	12.4
	Annual Operating	1.4	5.2	1.7	6.3

*Does not include recovery credits.

Tables 8-4 through 8-8 display the capital outlay expenditures and annualized costs for each regulatory alternative for model plants 1 through 5. All equipment associated with absorption/adsorption stripping columns are expressed as a fractional function of the major equipment costs in Table 8-9. From these initial investments, one can estimate such capital related charges as plant overhead, property taxes, insurance, and general administration; these charges are called fixed annual operating costs. To them are added recurring direct costs such as utilities, materials, and labor for operation and maintenance of the equipment during its life. These annual costs do not include the costs of capital and depreciation, raw materials, and distribution or selling costs. Table 8-10 provides the basis for estimating the annual operating costs for the regulatory alternatives for model plants 1 through 5; these estimates are presented in Tables 8-4 through 8-8. Credits for increased amounts of recovered solvent resulting from increased capture and control of solvent vapor are not presented.

8.3 MODIFIED OR RECONSTRUCTED FACILITIES

As defined in Chapter 5 of this report, synthetic fiber facilities may undergo "modification" or "reconstruction" thereby bringing the facility under the purview of the standard. Retrofitting solvent recovery equipment to existing synthetic fiber plants poses certain problems. The amount of physical space necessary to install ventilation ductwork to capture and transport solvent from process lines is a definite constraining factor. Equipment and personnel must be able to move along process line aisles without being excessively hindered; therefore, installation of enclosures at some existing facilities is not possible without a complete reconstruction of the entire spinning area.

Scrubbers, condensers, distillation columns, and carbon beds require additional utility distribution systems and larger load capacities to accommodate them. This could cause an overload problem at existing plants. Additional utility equipment may also pose space problems.

The cost of installing a control system in an existing plant that has been modified, reconstructed, or expanded may be greater than the cost of a system for a new facility with the same exhaust gas parameters because of special design considerations. In retrofitting systems,

Table 8-4. COMPONENT CAPITAL COSTS AND OPERATING COSTS FOR MODEL PLANT 1, ALTERNATIVE II AND III

	Component Capital Costs	
	Alternative II	Alternative III
Direct Costs	Dollars	Dollars
1) Equipment Costs		
Enclosures	605,000	806,500
Ducting	183,000	274,500
Adsorption/Stripping Columns	284,000	723,000
Fan, Pumps, Compressors	36,000	79,000
Instruments and Controls	16,600	28,200
Taxes	33,200	56,500
Freight	83,100	141,200
Total	1,240,900	2,108,900
2) Installation Direct Costs		
Foundations and Supports	133,000	226,000
Erection and Handling	664,800	1,129,800
Electrical	11,100	18,800
Piping	332,040	564,900
Insulation	11,100	18,800
Painting	11,100	18,800
Site Preparation	55,400	94,200
Facilities and Buildings	554,000	941,500
Total	1,772,900	3,012,800
3) Installation Indirect Costs		
Engineering and Supervision	166,200	282,500
Construction and Field Expenses	166,200	282,500
Construction Fees	221,600	376,600
Start-up	11,100	18,800
Performance Test	11,100	18,800
Contingencies	221,600	376,600
Total	797,800	1,355,800
Grand Total	$3,811,600	$6,477,500

	Operating Costs*	
	Alternative II	Alternative III
DIRECT OPERATING COSTS	Dollars	Dollars
1) Operating Labor		
a) Operator	54,000	54,000
b) Supervisor	8,100	8,100
2) Operating Materials	7,500	12,000
3) Maintenance		
a) Labor	54,000	54,000
b) Material	25,000	50,000
4) Utilities	152,500	306,800
5) Waste Disposal	38,100	64,800
INDIRECT OPERATING COSTS		
6) Overhead	117,800	142,900
7) Property Tax	38,100	64,800
8) Insurance	38,100	64,800
9) Administration	76,200	129,600
Total Cost	$609,400	$951,800
CREDITS		
10) Recovered Solvent	570,000 kg/yr	1,140,000 kg/yr

*Annualized capital costs not included; see Table 9-34.

Table 8-5. COMPONENT CAPITAL COSTS AND OPERATING COSTS FOR MODEL PLANT 2, ALTERNATIVE II AND III

	Component Capital Costs	
	Alternative II	Alternative III
Direct Costs	Dollars	Dollars
1) Equipment Costs		
Enclosures	484,000	605,000
Ducting	137,500	255,500
Adsorption/Stripping Columns	212,500	656,500
Fan, Pumps, Compressors	32,000	79,000
Instruments and Controls	13,000	23,900
Taxes	26,000	47,900
Freight	65,000	119,700
Total	970,000	1,787,500
2) Installation Direct Costs		
Foundations and Supports	104,000	191,500
Erection and Handling	519,600	957,600
Electrical	8,700	16,000
Piping	259,800	478,800
Insulation	8,700	15,900
Painting	8,700	16,000
Site Preparation	43,300	79,800
Facilities and Buildings	433,000	798,000
Total	1,385,600	2,553,600
3) Installation Indirect Costs		
Engineering and Supervision	129,900	239,400
Construction and Field Expenses	129,900	239,400
Construction Fees	173,200	319,200
Start-up	8,700	16,000
Performance Test	8,700	16,000
Contingencies	173,200	319,200
Total	623,500	1,149,200
Grand Total	$2,979,200	$5,490,300

	Operating Costs*	
	Alternative II	Alternative III
DIRECT OPERATING COSTS	Dollars	Dollars
1) Operating Labor		
a) Operator	54,000	54,000
b) Supervisor	8,100	8,100
2) Operating Materials	5,900	10,000
3) Maintenance		
a) Labor	54,000	54,000
b) Material	20,000	40,000
4) Utilities	119,200	319,200
5) Waste Disposal	29,800	48,000
INDIRECT OPERATING COSTS		
6) Overhead	113,000	133,000
7) Property Tax	29,800	55,000
8) Insurance	29,800	55,000
9) Administration	59,600	110,000
Total Costs	$523,200	$886,300
CREDITS		
10) Recovered Solvent	570,000 kg/yr	1,173,000 kg/yr

*Annualized capital costs not included; see Table 9-34.

Table 8-6. COMPONENT CAPITAL COSTS AND OPERATING COSTS FOR MODEL PLANT 3, ALTERNATIVE II AND III

	Component Capital Costs	
	Alternative II	Alternative III
Direct Costs	Dollars	Dollars
1) Equipment Costs		
Enclosures	--	248,000
Ducting	125,000	235,000
Adsorption/Stripping Columns	230,000	353,000
Fan, Pumps, Compressors	22,000	36,000
Instruments and Controls	5,700	13,100
Taxes	11,300	26,200
Freight	28,300	65,400
Total	422,300	976,700
2) Installation Direct Costs		
Foundations and Supports	45,200	104,600
Erection and Handling	226,200	523,200
Electrical	3,800	8,700
Piping	113,100	261,600
Insulation	3,800	8,700
Painting	3,800	8,700
Site Preparation	18,900	43,600
Facilities and Buildings	188,500	436,000
Total	603,300	1,395,100
3) Installation Indirect Costs		
Engineering and Supervision	56,500	130,800
Construction and Field Expenses	56,500	130,800
Construction Fees	75,400	174,400
Start-up	3,800	8,700
Performance Test	3,800	8,700
Contingencies	75,400	174,400
Total	271,400	627,800
Grand Total	$1,297,000	$2,999,600

	Operating Costs*	
	Alternative II	Alternative III
DIRECT OPERATING COSTS	Dollars	Dollars
1) Operating Labor		
a) Operator	54,000	54,000
b) Supervisor	8,100	8,100
2) Operating Materials	4,300	10,500
3) Maintenance		
a) Labor	54,000	54,000
b) Material	13,000	31,500
4) Utilities	45,200	134,000
5) Waste Disposal	12,900	30,000
INDIRECT OPERATING COSTS		
6) Overhead	105,900	124,400
7) Property Tax	12,900	30,000
8) Insurance	12,900	30,000
9) Administration	26,000	60,000
Total Costs	$349,200	$566,500
CREDITS		
10) Recovered Solvent	1,024,000 kg/yr	1,980,000 kg/yr

*Annualized capital costs not included; see Table 9-34.

Table 8-7. COMPONENT CAPITAL COSTS AND OPERATING COSTS FOR MODEL PLANT 4, ALTERNATIVE II AND III

	Component Capital Costs	
Direct Costs	Alternative II Dollars	Alternative III Dollars
1) Equipment Costs		
Enclosures	242,000	423,000
Ducting	120,000	180,000
Adsorption/Stripping Columns	650,000	820,000
Fan, Pumps, Compressors	100,000	125,000
Instruments and Controls	111,200	154,800
Taxes	33,400	46,500
Freight	83,400	116,100
Total	1,340,000	1,865,400
2) Installation Direct Costs		
Foundations and Supports	89,000	123,800
Erection and Handling	155,700	216,700
Electrical	44,500	61,900
Piping	22,200	30,900
Insulation	11,100	15,500
Painting	11,100	15,500
Site Preparation	55,600	77,400
Facilities and Buildings	556,000	774,000
Total	945,200	1,315,700
3) Installation Indirect Costs		
Engineering and Supervision	166,800	232,200
Construction and Field Expenses	83,400	116,100
Construction Fees	222,400	309,600
Start-up	22,200	30,900
Performance Test	11,100	15,500
Contingencies	222,400	309,600
Total	728,300	1,013,900
Grand Total	$3,013,500	$4,195,000

	Operating Costs*	
DIRECT OPERATING COSTS	Alternative II Dollars	Alternative III Dollars
1) Operating Labor		
a) Operator	54,000	54,000
b) Supervisor	8,100	8,100
2) Operating Materials	7,500	19,000
3) Maintenance		
a) Labor	54,000	54,000
b) Material	90,400	125,800
4) Utilities	42,300	105,000
5) Waste Disposal	30,100	41,900
INDIRECT OPERATING COSTS		
6) Overhead	176,800	166,600
7) Property Tax	30,100	41,900
8) Insurance	30,100	41,900
9) Administration	60,200	83,800
Subtotal	583,600	742,000
SHUTDOWN COSTS		
10) Labor and Lost Production	120,000	120,000
Total Costs	$703,600	862,000
CREDITS		
11) Recovered Solvent	1,140,000 kg/yr	1,620,000 kg/yr

*Annualized capital costs not included; see Table 9-37.

Table 8-8. COMPONENT CAPITAL COSTS AND OPERATING COSTS FOR MODEL PLANT 5, ALTERNATIVE II AND III

	Component Capital Costs Alternative II	 Alternative III
Direct Costs	Dollars	Dollars
1) Equipment Costs		
Enclosures	1,750,000	1,950,000
Ducting		
Adsorption/Stripping Columns	1,210,000	1,835,000
Fan, Pumps, Compressors	155,000	187,000
Instruments and Controls	46,700	59,600
Taxes	93,500	119,200
Freight	233,600	297,900
Total	3,488,800	4,448,700
2) Installation Direct Costs		
Foundations and Supports	249,200	317,700
Erection and Handling	436,100	556,000
Electrical	124,600	158,900
Piping	62,300	79,400
Insulation	31,200	39,700
Painting	31,200	39,700
Site Preparation	155,700	198,600
Facilities and Buildings	1,557,500	1,986,000
Total	2,647,800	3,376,000
3) Installation Indirect Costs		
Engineering and Supervision	467,300	595,800
Construction and Field Expenses	233,600	297,900
Construction Fees	623,000	794,400
Start-up	62,300	79,400
Performance Test	31,100	39,700
Contingencies	623,000	794,400
Total	2,040,300	2,601,600
Grand Total	$8,176,900	$10,426,300

	Operating Costs* Alternative II	 Alternative III
DIRECT OPERATING COSTS	Dollars	Dollars
1) Operating Labor		
a) Operator	54,000	54,000
b) Supervisor	8,100	8,100
2) Operating Materials	102,700	119,600
3) Maintenance		
a) Labor	54,000	54,000
b) Material	245,300	285,000
4) Utilities	205,300	239,100
5) Waste Disposal	81,800	104,300
INDIRECT OPERATING COSTS		
6) Overhead	331,700	371,400
7) Property Tax	81,800	104,300
8) Insurance	81,800	104,300
9) Administration	163,500	208,600
Total Costs	$1,410,000	$1,652,700
CREDITS		
10) Recovered Solvent	1,600,000 kg/yr	2,240,000 kg/yr

*Annualized capital costs not included; see Table 9-37.

TABLE 8-9. COMPONENT CAPITAL COST FACTORS
FOR ABSORPTION/ADSORPTION STRIPPING
AS A FUNCTION OF EQUIPMENT COSTS

Direct Costs	Absorption Factor	Adsorption Factor
Equipment, f.o.b. Manufacturer	1.000	1.000
Instruments and Controls	0.015	0.015
Taxes	0.030	0.030
Freight	0.075	0.075
Foundations and Supports	0.120	0.080
Erection and Handling	0.600	0.140
Electrical	0.010	0.040
Piping	0.300	0.020
Insulation	0.010	0.010
Painting	0.010	0.010
Site Preparation	0.050	0.050
Facilities and Buildings	0.500	0.500
Indirect Costs		
Engineering and Supervision	0.150	0.150
Construction and Field Expenses	0.150	0.075
Construction Fee	0.200	0.200
Start-up	0.010	0.020
Performance Test	0.010	0.010
Contingencies	0.200	0.200

NOTES: 1. Ducting costs include all ductwork, elbows, tees, expansion joints, dampers, and transition pieces of stainless steel.

2. Costs include stainless steel components on adsorbers, absorption column internals, distillation column internals, condensers, and piping where solvent liquid or vapor contacts surface.

3. Distillation columns are included as a cost of each control option regardless of solvent recovery method. This scenario was assumed in order to provide a worst-case cost. Critical design parameters for costing the distillation (stripping) columns included column diameter, number of plates, type and spacing of plates, operating pressure, heat input to the reboiler and heat output from the condenser.

TABLE 8-8. COMPONENT CAPITAL COST FACTORS FOR ABSORPTION/ADSORPTION STRIPPING AS A FUNCTION OF EQUIPMENT COSTS (Concluded)

NOTES: 4. Carbon adsorber costs are for basic custom built systems, not package units. Equipment costs include preconditioning, blowers, three adsorbers, activated carbon, condenser, storage tank, all process valves, distillation system, instrumentation/controls, and accessories.

5. Absorption and stripping columns are bubble cap tray and plate towers. The costs of absorption and stripping towers are a function of the size, thickness, and materials of construction. The design parameters used in costing include the column diameter, column height, operating pressure, column pressure drop, number of transfer units, tray efficiency, tray spacing, tray material, column shell material, thickness of shell wall, and liquid and gas flow rates. The cost of the fabricated vessel includes the cost of the shell plus the cost of two heads, a skirt for support, flange-type nozzles. To these are added the tray cost and support plates. Ancillary equipment such as fans and blowers are included under separate entry.

6. In order to avoid the potential build-up of an explosive concentration, air flow and solvent concentration monitoring instrumentation with machine shutdown capability are included in Model Plant 4 costs under "Instrument and Controls." Multiple monitors and numerous monitoring locations are incorporated for redundancy and added safety margin. Also included in the costs for "Fans, Pumps, Compressors" are the costs associated with back-up exhaust fans with power for operation received from two independent sources (e.g., electrical and steam turbine). Back-up may also involve a nonelectrical means of purging such as steam jet ejectors which could force the solvent/air mixture out of the enclosures. The equipment costs associated with the prevention of excessive risk amount to about 10 percent of the total capital cost of the control options.

7. Model Plant 5 costs for adsorption/stripping columns include extensive pretreatment of the gas stream for contaminant removal and dehumidification. The equipment consists of filter, cooler, and reheater to condition the gas before entering the adsorbers.

TABLE 8-10. BASIS FOR ESTIMATING ANNUAL OPERATING COSTS FOR REGULATORY ALTERNATIVES

Direct Operating Costs	
Operating Labor	
Direct Operator	$108,000/yr/man/shift
Supervision	15 percent of direct labor
Operating Materials	Per plant control process
Maintenance	
Labor	Equal to operating labor
Material	3 percent of total capital costs
Utilities	
Water	$0.25/1000 gal.
Electricity	$0.04/kWh
Steam	$4.0/1000 lbs.
Waste Disposal	1 percent of total capital costs
Indirect Operating Costs	
Overhead	80 percent of operating and maintenance labor plus maintenance materials
Property Tax	1 percent of total capital costs
Insurance	1 percent of total capital costs
Administration	2 percent of total capital costs
Credits	
Recovered Solvent	Dependent on specific plant process and recovery system

NOTE: Model Plant 4 annual operating cost includes the costs of shutdown of the spinning machines resulting from the application and use of enclosures on the spin cell exits and tow line. The costs represent the increased labor necessary to restart the machines and the production lost during the shutdown period.

additional costs may be encountered because of such items as demolition requirements, crowded construction working conditions, scheduling construction activities with production activities, and longer interconnecting piping. Availability of space, additional ducting, and additional engineering must be considered. These constraints must be taken into account when costing the retrofitting of recovery equipment at synthetic fiber plants. Estimating the additional installation cost or retrofit penalty is dependent on the many factors peculiar to the individual plant.

Configuration of equipment in the existing plant governs the location of the control system. Depending on process or stack location, long ducting runs from ground level to the control device, stack, and reprocessing equipment may be required. Costs may increase considerably if the control equipment must be placed on the roof and requires steel structural support. It is estimated that rooftop installation can double the structural costs. In addition, labor would probably have to be done at premium wage rates in accordance with governmental regulations and/or union agreements. Other cost components that may increase because of space restrictions and plant configurations are contractor's fees and engineering fees, which are estimated at 15 percent and 20 percent for a new facility, but may be expected to increase to 20 percent and 30 percent for a retrofit. These fees depend on the difficulty of the job, the risks involved, and the current economic conditions.

The annual operating costs of control systems for modified/reconstructed facilities are calculated similarly to those for new facilities. The cost items may be equal to or greater than costs for new facilities, depending on the specific layout of the control equipment and affected facility.

8.4 COST EFFECTIVENESS

8.4.1 Model Plants

Cost effectiveness, expressed in annualized costs per megagram of emission reduction, for Regulatory Alternatives II and III for model plants 1 through 5 are presented in Tables 8-11, 8-12, and 8-13. All costs, production levels, emission reductions, etc., are based on model plant parameters described in Chapters 6 and 8.

Under Alternative II, model plant 1 shows a zero cost effectiveness when compared to baseline, Alternative I; the costs of controls for emission reduction are offset by the value of the recovered solvent. Model plant 3 shows a net gain of $182/Mg under Alternative II; the additional solvent that could be recovered beyond baseline would result in decreased annualized costs. Model plants 2, 4, and 5 show positive cost effectiveness of $166, $166, and $588 per Mg VOC reduction, respectively, when compared to Alternative I.

Under Alternative III, model plants 1 and 3 show a net gain or annual savings of $350 and $193 per Mg of emission reduction, respectively, when compared to the baseline. Model plant 2 would experience a zero cost effectiveness under this alternative. However, model plants 4 and 5 would incur positive increases in annual costs of $120 and $442 per Mg of emission reduction, respectively, above the baseline case.

Compared to Alternative II, the application of Alternative III to the model plants would result in decreased annualized costs of control and thus in decreasing cost per Mg of emission reduction, as presented in Table 8-13.

8.4.2 Projected 1987 Cost Effectiveness

The projected capacity shortfalls as presented in Tables 9-20 and 9-30 of Chapter 9 lead to the following conclusions concerning likely capacity additions by synthetic fiber producers by 1987:

(1) The projected capacity shortfall arising from the high growth projection for acrylic and modacrylic fibers would support additional plant capacity. For this analysis, it is assumed that capacity is constructed in increments of model plant capacity, and that plants of model plant 2 type would be built. Two plants, each with 45.36 Gg capacity, would be constructed by 1987 since there would be significant capacity shortfall if only one were constructed. These two plants would each operate at 81 percent capacity utilization in 1987. (Table 9-11 in this BID indicates that this capacity utilization rate is well within the range of historical values.)

Table 8-11. REGULATORY ALTERNATIVE II COST EFFECTIVENESS COMPARED TO BASELINE COSTS

Model Plant	Production Capacity (Gg/yr)	Baseline Emission Factor (kg VOC/Mg Fiber)	Baseline[a] Emission (Gg/yr)	Baseline[b] Annual Cost (10^6\$/yr)	Alternative II					
					Emission Factor (kg VOC/Mg Fiber)	Emissions (Gg/yr)	Annual[c] Cost (10^6\$/yr)	Emission Reduction (Gg)	Cost Increase (10^6\$/yr)	Cost Effectiveness (\$/Mg)
1	45.36	40	1.7	61.3	26	1.1	61.3	0.6	0.0	0
2	45.36	45	1.9	54.5	31	1.3	54.6	0.6	0.1	166
3	20.0	140	2.7	28.0	86	1.6	27.8	1.1	(0.2)	(182)
4	22.7	120	2.6	32.0	67	1.4	32.2	1.2	0.2	166
5	22.7	145	3.1	35.1	66	1.4	36.1	1.7	1.0	588

[a] @ 95% capacity.

[b] Does not include polymer costs, but does include solvent costs and annualized capital costs (depreciation plus cost of capital. See Tables 9-34 and 9-37.)

[c] Includes solvent costs and annualized capital costs, but does not include polymer costs.

Table 8-12. REGULATORY ALTERNATIVE III COST EFFECTIVENESS COMPARED TO BASELINE COSTS

Model Plant	Production Capacity (Gg/yr)	Baseline Emission Factor (kg VOC/Mg Fiber)	Baseline[a] Emission (Gg/yr)	Baseline[b] Annual Cost (10^6\$/yr)	Alternative III					
					Emission Factor (kg VOC/Mg Fiber)	Emissions (Gg/yr)	Annual[c] Cost (10^6\$/yr)	Emission Reduction (Gg)	Cost Increase (10^6\$/yr)	Cost Effectiveness (\$/Mg)
1	45.36	40	1.7	61.3	13	0.56	60.9	1.14	(0.4)	(350)
2	45.36	45	1.9	54.5	18	0.78	54.5	1.12	0.0	0
3	20.0	140	2.7	28.0	33	0.63	27.6	2.07	(0.4)	(193)
4	22.7	120	2.6	32.0	44	0.95	32.2	1.65	0.2	120
5	22.7	145	3.1	35.1	40	0.86	36.1	2.26	1.0	442

[a] @ 95% capacity.

[b] Does not include polymer costs, but does inlcude solvent costs and annualized capital costs (depreciation plus cost of capital. See Tables 9-34 and 9-37.)

[c] Includes solvent costs and annualized capital costs, but does not include polymer costs.

Table 8-13. COMPARISON OF COST-EFFECTIVENESS OF REGULATORY ALTERNATIVES II AND III

Model Plant	Alternative II Emissions (Gg/yr)	Alternative III Emissions (Gg/yr)	Alternative II Annual Cost (10^6\$/yr)	Alternative III Annual Cost (10^6\$/yr)	Emission (Alternative III-Alternative II) (Gg/yr)	Annual Cost (10^6\$/yr)	Cost Effectiveness (\$/Mg)
1	1.1	0.56	61.3	60.9	0.54	(0.4)	(740)
2	1.3	0.78	54.6	54.5	0.52	(0.1)	(190)
3	1.6	0.63	27.8	27.6	0.97	(0.2)	(206)
4	1.4	0.95	32.2	32.2	0.46	N/A	N/A
5	1.8	1.35	36.1	36.1	0.44	N/A	N/A

(2) The projected capacity shortfall arising from the low growth projection for acrylic and modacrylic fibers would not support additional capacity. This shortfall would likely be met by debottlenecking current production processes.

(3) The projected capacity shortfall arising from the high growth projection for cigarette filtration tow would support additional capacity by 1987. Again, it is assumed that capacity is constructed in increments of model plant capacity. Four plants, each with 22.7 Gg capacity, would be constructed. These four plants would each operate at 95 percent capacity utilization. A capacity shortfall of 4.3 Gg would still exist, but this shortfall would not support an additional plant.

(4) The projected capacity shortfall arising from the low growth projection for cigarette filtration tow would also support additional plant capacity by 1987 (capacity that would be constructed in increments of model plant capacity). Two plants, each with 22.7 Gg capacity, would be constructed. These two plants would each operate at 95 percent capacity utilization. Excess capacity of 1.7 Gg would exist.

(5) The projected capacity shortfalls arising from either the high or low growth projections for cellulose acetate textile yarn would not support additional capacity by 1987.

Based on the above conclusions, comparisons of annualized costs per megagram of emission reduction were made for those plants that are most likely to be built in the next 5 years. All three regulatory alternatives were examined. Compared to the baseline, Alternatives II and III result in emission reductions of 5.6 and 8.5 Gg/year, respectively, by 1987. Using these emission reduction figures, annualized costs per megagram of emission reduction for typical plants would be as much as $392 and $202, respectively, for Alternatives II and III.

At these same plants, Alternative III would result in an annual total emission reduction of about 3.0 Gg/year more than Alternative II. Alternative III would have an annual cost of $2.4 million more than Alternative II; however, the value of the additional solvent recovered would decrease the annual cost by roughly the same amount. Thus, there would be no net cost per megagram of emission reduction to the industry in implementing Alternative III over Alternative II. Table 8-14 presents the projected 1987 cost effectiveness of the regulatory alternatives.

Table 8-14. PROJECTED 1987 COST EFFECTIVENESS OF REGULATORY ALTERNATIVES

	Acrylic/Modacrylic		Cellulose Acetate Filter Tow		Totals	
Growth Scenario 1982-1987	high	low	high	low	high	low
Number of Affected Facilities 1987	2	0	4	2	6	2
Alternative II* Solvent Credit ($10^6\$$)	1.1	0.0	3.0	1.5	4.1	1.5
Alternative III[1] Solvent Credit	2.2	0.0	4.3	2.1	6.5	2.1
Baseline Annual Cost ($10^6\$/\mathrm{yr}$)	108.0	0.0	128.0	64.0	236.0	64.0
Alternative II Annual Cost ($10^6\$/\mathrm{yr}$)	108.4	0.0	128.8	64.4	237.2	64.4
Alternative III Annual Cost ($10^6\$/\mathrm{yr}$)	108.4	0.0	128.8	64.4	237.2	64.4
Alternative II Net Annual Cost ($10^6\$/\mathrm{yr}$)	0.4	0.0	0.8	0.4	1.2	0.4
Alternative III Net Annual Cost ($10^6\$/\mathrm{yr}$)	0.4	0.0	0.8	0.4	1.2	0.4
Alternative II Emission Reduction (Mg)	1020	---	4570	2280	5590	2280
Alternative III Emission Reduction (Mg)	1980	---	6560	3280	8540	3280
Alternative II Cost Effectiveness ($/Mg)	392	---	175	175	215	175
Alternative III Cost Effectiveness ($/Mg)	202	---	122	122	141	122

*Amount of solvent recovered multiplied by solvent cost, \$1.09/kg DMF and \$0.62/kg acetone.

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9.0 ECONOMIC IMPACT

9.1 INDUSTRY CHARACTERIZATION

9.1.1 Industry Overview

Manmade fibers are of two types: cellulosic, and noncellulosic or synthetic. Data on the production of cellulosic fibers are classified by the U.S. Department of Commerce in Standard Industrial Classification (SIC) code 2823, Cellulosic Manmade Fibers. Data on the production of noncellulosic fibers are classified in SIC 2824, Synthetic Organic Fibers, Except Cellulosic. Cellulosic fibers are known generically as cellulose acetate, cellulose triacetate, and rayon. They are produced from cellulose, the fibrous substance in plants, especially that derived from spruce and other soft woods. Most noncellulosic fibers are polyester, nylon, acrylic, modacrylic, or polyolefin. The feedstocks for these fibers are polymerized petroleum derivatives. The three types of cellulosic fibers, together with these five types of noncellulosic fibers, currently comprise approximately 99 percent of manmade fiber production.

The first manmade fiber manufactured in the United States was rayon in 1910. By 1930, U.S. production of rayon, acetate, rubber, glass, nylon, and vinyon supplied 10 percent of the fibers used by domestic textile mills. Commercial production of saran (1941), metallic (1946), modacrylic (1949), acrylic (1950), polyester (1953), triacetate (1954), spandex (1959), aramid (1961), and olefin (1961) fibers followed. By 1979 manmade fibers comprised 75 percent (4,413.8 gigagrams*) of domestic mill consumption. The use of cotton fiber by U.S. mills declined from 81 percent to 24 percent over the period 1940-1979; the use of wool declined from 8 percent to less than 1 percent.[1]

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*One gigagram equals 1,000 megagrams or 2,207 x 10^3 pounds.

The most significant growth in the manmade fibers industry occurred between World War II and the 1974-75 recession. Historical production data by fiber type are presented in Table 9-1. Data for 1979 are presented in absolute and percentage terms to illustrate the relative importance of each fiber type by quantity of production. Table 9-2 provides quantity of production and value of shipments data by fiber type for 1977, the most recent year for which value of shipments data are available. Nylon fiber prices have historically exceeded polyester fiber prices, causing an incongruity in percentage of production and percentage of value data.

9.1.1.1 Role of the Synthetic Fibers Industry in the U.S. Economy. The shares of GNP, employment, and new capital expenditures contributed by the manmade fibers industry to the national economy provide a measure of the industry's significance. The most recent data available to calculate these shares are published by the U.S. Department of Commerce. Industry data were obtained by summing the relevant variables from SIC 2823, Cellulosic Manmade Fibers, and SIC 2824, Synthetic Organic Fibers, Except Cellulosic, from the 1977 Census of Manufactures. Domestic economy aggregates were obtained from the Survey of Current Business.

In 1977, the manmade fibers industry supplied 0.17 of 1 percent of GNP and 0.1 of 1 percent of total employment. New capital expenditures by the industry were 0.27 of 1 percent of expenditures on new plant and equipment by all industries that year.

These ratios underestimate the overall significance of manmade fibers in the economy. As intermediate products, the fibers have important interindustry linkages. They supply approximately three-fourths of the fiber (by weight) used by domestic textile mills, which in turn supply apparel, home-furnishings, and industrial markets. Most types of manmade fibers have other end uses as well. For example, about half of the production of cellulose acetate is consumed as cigarette filtration tow. Nylon fibers are used in air hoses, racket strings, ropes and nets, tire cord, and thread. Olefin fibers are used to produce nonwoven felts, ropes and cordage, and sewing thread. Rayon has applications in medical and surgical products (it is no longer

TABLE 9-1. U.S. MANMADE FIBER PRODUCTION[2] [3] [4]
(gigagrams)

Fiber type	1960			1970			1979			
	Yarn and monofilaments	Staple and tow	Total	Yarn and monofilaments	Staple and tow	Total	Yarn and monofilaments	Staple and tow	Total	Fiber type as percent of total
Cellulosic fibers										
Rayon	193.4	142.4	335.8	121.4	275.5	396.9	25.8	249.2	275.0	6.2
Acetate[a]										
Textile fiber	103.5	27.2	130.7	210.1	15.9	226.0	143.6	3.2	146.8	3.3
Cigarette filtration tow	0.0	48.9	48.9	0.0	83.8	83.8	0.0	165.3	165.3	3.7
Noncellulosic fibers										
Nylon and aramid	174.5	12.2	186.7	516.1	98.3	614.5	808.1	425.8	1,234.0	28.0
Acrylic and modacrylic	0.0	61.6	61.6	0.0	223.1	223.1	0.0	345.2	345.2	7.8
Olefin	6.2	0.0	6.2	90.9	26.7	117.6	289.9	52.8	342.7	7.8
Polyester		34.1	52.7		463.7	671.5	778.2	1,116.8	1,895.0	42.9
Other[b,c]	17.6	1.0		206.4	1.4		8.2	1.7	9.8	0.2
Total			822.6			2,333.4			4,413.8	

[a] Acetate includes diacetate and triacetate.

[b] Other includes spandex, TFE-fluorocarbon (Teflon®), and vinyon.

[c] For 1960 and 1970, polyester yarn and monofilaments are included in "Other" category.

TABLE 9-2. VALUE OF SHIPMENTS BY FIBER TYPE, 1977[5]

Fiber type	Production (gigagrams)[a]	Percent of total	Value of shipments[b] (million dollars)	Percent of total
Nylon fibers, except producer textured	1,053.7 (2,326.1)	29.5	1,962.9	37.4
Polyester fibers, except producer textured	1,649.9 (3,642.2)	46.2	1,938.6	36.9
Rayon and acetate fibers	548.0 (1,209.7)	15.3	851.1	16.2
Acrylic and modacrylic fibers, except producer textured	321.1 (708.8)	9.0	495.8	9.4
Total	3,572.7 (7,886.8)	100.0	5,248.4	99.9

[a] Numbers in parentheses are in million pounds.

[b] Does not include values of shipments of $1,074.2 million attributed to shipments of other noncellulosic manmade fibers (olefin, saran, spandex, vinyon, fluorocarbon, etc.), producer-textured manmade fibers, group filament, and noncellulosic organic fibers, not specified by kind.

used in the production of tire cord). Modacrylics are used to produce filters, paint rollers, and wigs, in addition to their more prevalent use in textiles manufacture.

Some manmade fibers such as aramid and vinyon are consumed entirely by markets other than the textile industry. Aramid fibers are used to produce tires, ropes and cables, mechanical rubber goods (such as gaskets) and structural supports for aircraft and boats. Vinyon fibers are used primarily by industries as a bonding agent for nonwoven fabrics and products. None of the manmade fibers has any significant final (as opposed to intermediate) demand.

The manufacture of manmade fibers consumes intermediate goods produced by other industries, most significantly the petrochemical and organic chemicals industry. Data on the most important materials used by the noncellulosic and cellulosic fibers industries are provided in the 1977 Census of Manufactures. Principal material inputs include synthetic organic chemicals (especially acetic anhydride, acrylates and methacrylates, acrylonitrile and glycols), inorganic chemicals (especially sodium hydroxide and sulphuric acid), plastic resins (especially polypropylene and nylon resins), liquified petroleum and refinery gases (ethane and ethylene, propane and propylene, butane, butylene, and isobutane), natural gas, and paper and paperboard containers. Producers of cellulosic fibers additionally purchase a significant amount of wood pulp.

9.1.1.2 The Synthetic Fibers of Interest. Fiber polymer is extruded through three major processes: melt spinning, wet spinning, (including reaction spinning) and dry spinning.* In wet and dry spinning, the fiber polymer must be dissolved in a solvent to produce an extrudable solution. The principal fibers produced by wet or dry spinning are acrylics, modacrylics, and all cellulosics. The solvents used to dissolve the fiber polymers are of two generic types, volatile organic compounds (VOCs) and aqueous salts. The use of VOCs results in fugitive emissions of the hazardous chemicals along the process line. Approximately 77 percent of current production capacity[6,7] for acrylic and modacrylic fibers and all production capacity[8] for cellulose acetate and triacetate fibers use volatile organic solvents.

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*A more detailed description of the production processes for each of the manmade fibers is contained in Chapter 3.

Nylon, polyster, and olefin fibers are produced by melt spinning, which uses heat rather than solvent to melt the fiber polymer for extrusion. Melt spinning can be used for these fibers because heat does not degrade the polymers. Because no solvent is needed, emissions of volatile organic solvents do not occur.

Wet spinning (but not including reaction spinning) and dry spinning, which use volatile organic chemicals as solvents, are the production processes for which the EPA recommends further control of VOC emissions. Manmade fibers falling under these proposed New Source Performance Standards (NSPS) include cellulose acetate and triacetate, acrylic and modacrylic, and some specialty fibers such as vinyon that are produced in relatively small amounts. Although some spandex fibers are produced by dry spinning, production of this fiber will not be affected by the NSPS because these plants already meet the recommended levels of emission control. Rayon fibers are currently produced by the viscose process, which is a significant source of carbon disulfide and hydrogen sulfide emissions. However, the EPA was unable to identify control technology that would result in emission reductions beyond existing control levels. Furthermore, industry sources report that in all likelihood there will be no further expansion of viscose rayon capacity. New nonviscose processes, which do not require the use of sulfur-containing compounds are being developed, and it appears that producers of rayon will not increase capacity until a nonviscose process can be implemented. Viscose rayon processes have therefore been excluded from the source category subject to the proposed NSPS.

Model plants reflecting new capacity in the acrylics and modacrylics industry and the cellulose acetate industry were constructed by the EPA. Costs for the model plants were estimated for three alternative levels of VOC control. A profile of each of these two industries is provided as the first step in the economic analysis.

9.1.2 Acrylic and Modacrylic Fibers

9.1.2.1 Production

9.1.2.1.1 Product description. Acrylic and modacrylic fibers are noncellulosic (synthetic) fibers produced from the polymer polyacrylonitrile. Polyacrylonitrile is made from acrylonitrile, a propylene and ammonia derivative. Acrylic fibers are defined by the U.S. Federal Trade Commission as "manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85 percent by weight of acrylonitrile units."[9] The remaining 15 percent or less of the fiber consists of comonomers, generally acrylates, methacrylates, or vinyl monomers. Modacrylic fibers are defined as formed from a polymer composed of "less than 85 percent but at least 35 percent by weight of acrylonitrile units, except fibers qualifying as lastrile or anidex."[9] Modacrylic fibers are made from copolymers consisting of polyacrylonitrile and other materials such as vinylidene chloride, vinyl chloride or vinylidene dicyanide.

9.1.2.1.2 Production technology.* Acrylonitrile is converted into fiber polymer through suspension polymerization or solution polymerization. All acrylic fibers and approximately half of modacrylic fibers domestically produced are manufactured through suspension polymerization.

In suspension polymerization acrylonitrile and comonomers are polymerized in the presence of a catalyst. Insoluble beads of polyacrylonitrile polymer are formed that must be dissolved in a solvent to produce an extrudable solution. Monomers are recovered from the filtration and washing steps and recycled to the polymerization reactors.

In solution polymerization, acrylonitrile and comonomers are dissolved in either an organic solvent such as dimethylformamide (DMF), dimethylacetamide (DMAc) or acetone, or in a concentrated aqueous solution of sodium thiocyanate (NaSCN) or zinc chloride ($ZnCl_2$). A catalyst is added to initiate the polymerization reaction. The polyacrylonitrile formed is soluble and therefore extrudable. The filtration, washing, drying, grinding, and redissolving steps that follow suspension polymerization are avoided.

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*All information on production processes has been taken from Chapter 3.

After polymerization, the solution is extruded through spinnerets to form filaments. During the extrusion process, the solvent in which the polyacrylonitrile was dissolved is removed. The polymer resolidifies, forming fibers. Approximately 55 percent of domestic acrylic fibers and 30 percent of domestic modacrylic fibers are produced by wet spinning; the remainder are produced by dry spinning.

In wet spinning, the solution is extruded into a spinning bath containing solvent and water. The diffusion of solvent from the filament to the bath, and the diffusion of water to the filaments results in a swollen gel filament that must be densified in post-treatment of the fibers.

In dry spinning, the polyacrylonitrile in solvent is extruded through a spinneret into a column of hot inert gas. Acetone and DMF are the preferred solvents for polymer solutions that are dry spun. As the solvent evaporates, the filaments solidify. The solvent is condensed in a solvent recovery section and recycled to the dissolving step. Both wet- and dry-spun fibers require washing, drawing, finishing, crimping, drying, stapling, and packing.

Regardless of the polymerization or extrusion process, solvent is captured and reused. Volatile organic solvent is captured by precipitation or enclosures, scrubbed, and returned to the polymerization, dissolving and spinning steps. Aqueous salt solvents (used only in wet spinning) are recovered by precipitating the solvent from the used solvent bath in a captive wastewater treatment facility.

Domestic acrylic and modacrylic fiber producers perform at least polymerization of the input acrylonitrile. Only two producers purchase acrylonitrile; the rest manufacture it from captive or purchased propylene and ammonia.[10] The producers spin, cut, crimp, and bale the fiber. None of the producers are integrated forward to the manufacture of textiles.

For the most part, the production technology is well established; however, variations exist. As noted previously, either suspension or solution polymerization may be used. Polymerization may be either batch mode or continuous regardless of the polymerization process. The solvent used to dissolve the polymer may be either a volatile organic compound or an aqueous salt. The production technology is available for sale by the producers.

9.1.2.1.3 Production history. Modacrylic fibers were first commercially produced in the United States in 1949 by Union Carbide Corporation. Acrylic fibers in the form of continuous monofilament yarns were first produced in 1950 by E. I. du Pont de Nemours & Company, Inc. Du Pont began producing acrylic staple in 1952, and discontinued production of acrylic monofilament yarn in 1956. Only small amounts have been produced since that time. Data on annual domestic production of acrylics and modacrylics for the period 1960-1980 are presented in Table 9-3. Production of acrylic and modacrylic continuous filament yarn has never been significant, and therefore data are not available. Acrylic continuous filament yarn production from 1950 to 1956 and 1963 to 1965, and modacrylic yarn production from 1948 to 1954, is believed to have totaled little more than one fifth a gigagram (less than one half million pounds) annually.[13] Between 1960 and 1973, output increased from 61.5 to 336.2 gigagrams, but it declined in 1974 and 1975, falling to 237.6 gigagrams. Since 1975, production has steadily increased, rising to 353.4 gigagrams in 1980. The decline in output from 1973 to 1975 is explained by higher input (propylene) prices and decreased demand due to the worldwide recession occurring in those years.

9.1.2.1.4 Role in U.S. economy. The acrylics and modacrylics fiber industry contributed 0.0001 of 1 percent of total GNP, 0.006 of 1 percent of total employment, and 0.003 of 1 percent of expenditures on new plant and equipment by all industries in 1977.

These ratios are not mathematically significant from zero given the accuracy of the data from which they were calculated. As a measure of the importance of the acrylic and modacrylics industry to the aggregate economy, these ratios are misleading. Because acrylic and modacrylic fibers are intermediate products, the industry functions as both a demander of outputs of certain industries and a supplier of inputs to other industries.

TABLE 9-3. DOMESTIC PRODUCTION OF ACRYLIC AND MODACRYLIC STAPLE, TOW AND FIBERFILL (EXCLUDING WASTE)[11 12]

	Production	
	(gigagrams)	(million pounds)
1960	61.5	135.7
1961	63.5	140.1
1962	77.0	170.0
1963	95.0	209.7
1964	130.3	287.7
1965	166.9	368.4
1966	159.9	352.9
1967	180.2	397.7
1968	236.0	521.0
1969	241.4	533.0
1970	222.8	491.9
1971	247.0	545.2
1972	283.5	625.9
1973	336.2	742.1
1974	285.9	631.2
1975	237.6	524.6
1976	281.3	621.0
1977	321.1	708.8
1978	328.7	725.7
1979	344.8	761.1
1980	353.4	779.2

The most significant purchases by acrylic and modacrylic fiber producers are acrylonitrile or the inputs to its production (propylene and ammonia) and solvents such as acetone, DMAc, DMF, and aqueous salts. The most significant market for acrylic and modacrylic fibers is the textile industry, specifically knitting and weaving mills, and carpet and rug manufacturers. Textiles produced from acrylic and modacrylic fibers in turn supply manufacturers of apparel, blankets, and draperies and curtains. Acrylic and modacrylic fibers compete primarily with the wool industry in supplying the apparel market and the nylon and polyester industries in supplying the home-furnishings market.

9.1.2.1.5 Factors of production. Acrylonitrile, the basic raw material of acrylic and modacrylic fiber production, is produced by reacting a mixture of propylene, ammonia, and air in the presence of a catalyst. Acrylonitrile is used as an intermediate in the production of acrylic and modacrylic fibers, acrylonitrile-butadiene-styrene (ABS) resins, styrene-acrylonitrile (SAN) resins, nitrile elastomers, adiponitrile (a raw material in Nylon 66), and acrylamide monomers and polymers.

In 1979, approximately 39 percent of the acrylonitrile produced domestically was used in the manufacture of acrylic and modacrylic fibers. Another 17 percent was used to produce resins such as ABS, 3 percent was used in nitrile elastomers, and 20 percent was used in miscellaneous applications including the manufacture of intermediates (such as adiponitrile) for the production of nylon. The residual 21 percent was exported.[14]

Currently, four firms manufacture acrylonitrile; three are also producers of acrylic and modacrylic fibers. Table 9-4 lists these producers, their plant locations, and plant capacities as of January 1, 1981. Two other firms have discontinued production of acrylonitrile. Union Carbide produced acrylonitrile between 1954 and 1966 in a small-scale operation in Institute, West Virginia. B. F. Goodrich produced acrylonitrile in a pilot plant at the Avon Lake Technological Center in the 1950s and in Calvert City, Kentucky, from 1954 to 1972. Both companies discontinued manufacture of the product because their

TABLE 9-4. DOMESTIC PRODUCERS OF ACRYLONITRILE, 1981[15]

Company	Plant location	Annual capacity (gigagrams)	Annual capacity (million pounds)
American Cyanamid Co.			
Indust. Chems. Div.	New Orleans, LA	120	265
E. I. du Pont de Nemours & Co., Inc.			
Petrochems. Dept.			
Freon® Products Div.	Memphis, TN	122	270
Polymer Intermediates Dept.	Beaumont, TX	159	350
Monsanto Co.			
Monsanto Chem. Intermediates Co.	Chocolate Bayou, TX	209	460
	Texas City, TX	204[a]	450[a]
Standard Oil Co. of Ohio			
Vistron Corp., Subsid.			
Chems. Dept.	Lima, OH	181[b]	400[b]
	Total	995	2,195

[a] An additional 102 gigagrams-per-year (225 million pounds-per-year) facility is in place but not operational.

[b] Includes 45 gigagrams (100 million pounds) of older capacity that can be run or placed on standby depending upon market conditions.

plant capacities were too small to be competitive with the larger producers.[16]

As indicated by Table 9-4, Monsanto Company recently expanded its acrylonitrile capacity by 50 percent. Two other acrylonitrile producers are in the process of constructing new plant capacity. Du Pont has an acrylonitrile plant under construction at Victoria, Texas, that is to be completed by the fourth quarter of 1982. The new plant is intended to replace existing capacity. Standard Oil Company of Ohio's subsidiary, Vistron Corporation, has additional capacity of 181 gigagrams per year under construction at Green Lake, Texas. The plant is expected to be completed in the fourth quarter of 1981.[17]

Both Eastman Kodak Company (Tennessee Eastman) and Monsanto are increasing propylene production capacity. Eastman Kodak began adding 50 percent to its current capacity of 181 gigagrams per year in 1981; Monsanto has recently doubled its current capacity of 249 gigagrams per year in a joint venture with Conoco, Inc.[17]

Production of modacrylic fibers requires chlorinated vinyl comonomers in addition to acrylonitrile as inputs to polymerization. None of the modacrylic fiber producers manufactures its own comonomers.

The other raw materials used in acrylic and modacrylic fiber production are primarily solvent and finish. The solvents used by domestic producers of acrylic fibers are aqueous NaSCN and $ZnCl_2$, DMF and DMAc. Solvents used by domestic producers of modacrylic fibers are DMF, DMAc, and acetone.[7]

Du Pont manufactures both DMAc and DMF.[19] The firm utilizes DMF in its production of both acrylic and modacrylic fibers. Monsanto purchases DMAc for its production of the two fibers. American Cyanamid Company and Badische Corporation produce only acrylic fibers; they use an aqueous salt (NaSCN) and zinc chloride, respectively, for solvent.[7] Tennessee Eastman, which produces only modacrylic noncellulosic fibers, uses captively produced acetone as a solvent for these fibers and for its cellulose acetate textile fibers and cigarette filtration tow.

The final raw material used in the production of acrylic and modacrylic fibers is finish. The cost and availability of finish were determined by the EPA to have negligible impacts on production.

The 1977 Census of Manufactures reports that 5,700 persons are employed in plants primarily producing acrylic and modacrylic fibers.* Production workers involved in the polymerization and spinning steps are semiskilled and are trained on the job for 1 year. There are usually two production workers per spinning line; acrylic and modacrylic fiber production is capital rather than labor intensive.

Producers of acrylic and modacrylic fibers can easily switch between production of the two fibers. Although raw materials differ--production of modacrylic fiber requires a copolymer of acrylonitrile and a chlorinated vinyl comonomer, and production of acrylic fiber requires a polyacrylonitrile polymer--both fibers are produced with solvents such as DMF, DMAc, or acetone. Processes for dissolving the polymer in solvent and spinning the fibers are interchangeable between the two types of fiber; therefore, the same capital machinery can be used for both. Indeed, Eastman Kodak is reported to use the same polymerization, solution preparation, and spinning equipment to manufacture both modacrylic and cellulose acetate fibers; hence the use of acetone as the solvent for both fiber types. Polymerization and extrusion facilities are general to all fiber types. Machinery for texturizing and cutting tow is specific to staple production; machinery for spinning yarns from staple fibers is specific to yarn production.

The relative amounts of acrylonitrile and comonomer, and the relative amounts of polymer and solvent, used to produce acrylic and modacrylic fibers may be varied, yielding fibers with distinct characteristics. For example, the chlorinated vinyl comonomers used in modacrylic fiber production may be used to produce flame-resistant fibers. The relative amounts of polymer and solvent employed in wet spinning are varied according to the denier of fiber being manufactured. There does not appear to be much potential for the substitution of capital for labor in the polymerization and spinning processes of acrylic and modacrylic fibers. Substitution of capital equipment for solvent is evidenced by the increased recovery rate of solvent resulting from emissions control equipment.

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*This employment figure is subject to error in both directions due to the Census method of classifying plants by primary product. First, the figure excludes employment in plants that manufacture acrylic and modacrylic fibers as a secondary product. Second, the figure includes employment that is not related to acrylic or modacrylic production in plants that manufacture acrylic or modacrylic fibers as a primary product.

9.1.2.2 Supply Conditions. The most recent data for domestic shipments of acrylic and modacrylic staple, tow, and waste fiber disaggregated by apparel, home-furnishings, and industrial end uses indicate that apparel consumed 68 percent of acrylic and modacrylic fibers in 1975.[20] Acrylic and modacrylic fibers were primarily used to produce craft yarns; sweaters; pile fabrics; top-type fabrics for shirts, blouses, and light-weight dresses; anklets and socks; and bottom-type fabrics for pants, sportswear, and tailored clothing. In the home-furnishings market, which consumed almost 27 percent of acrylic and modacrylic staple, tow, and waste fibers, the primary end uses were carpets, rugs, and blankets. The residual industrial uses were primarily doll hair and fabric for toys, fiberfill, and stuffing. Table 9-5 provides a breakdown of domestic shipments by acrylic and modacrylic staple and tow for the years 1970-1975. The primary distinctions of modacrylic fibers compared to acrylic fibers are that they duplicate more closely the feel and appearance of natural fur, they dye more easily and, due to the comonomers present in the polymer, they may be modified to be flame resistant. A more detailed analysis of the end uses for acrylic and modacrylic fibers is provided in Section 9.1.2.3.

Acrylic and modacrylic fabrics are produced from high-bulked yarns spun from staple. The yarns are combinations of high- and low-shrinkage staple. Applying heat to the yarn causes the high-shrinkage staple to squeeze the low-shrinkage staple to the surface, making the yarn bulky, fluffy, and soft. Mechanically crimping the staple fiber gives the yarn even more bulk. Therefore, the demand is for acrylic and modacrylic staple fiber, and production of continuous monofilament yarn has been discontinued.

Table 9-6 illustrates the relative magnitude of production of acrylic and modacrylic fibers. The table indicates that after the first few years, relative production stabilized at a bit more than 90 percent acrylic fiber.

TABLE 9-5. TOTAL SHIPMENTS OF ACRYLIC AND MODACRYLIC STAPLE AND TOW[21]
(gigagrams)

Year	Acrylic	Modacrylic	Total[a]
1970	201.8	17.8	219.6
1971	223.4	16.9	240.2
1972	266.3	19.1	285.4
1973	316.2	30.0	346.2
1974	246.4	23.1	269.5
1975	233.4	17.4	250.8

[a] Excludes waste; includes domestic shipments and exports.

[illegible]

[illegible]

[illegible]

	ACRYLIC	MODACRYLIC	TOTAL	ACRYLIC AS PERCENT OF TOTAL
1948	[illegible]	[illegible]	[illegible]	[illegible]
1949	[illegible]	[illegible]	[illegible]	[illegible]
1950	[illegible]	[illegible]	[illegible]	[illegible]
1951	[illegible]	[illegible]	[illegible]	[illegible]
1952	[illegible]	[illegible]	[illegible]	[illegible]
1953	[illegible]	[illegible]	[illegible]	[illegible]
1954	[illegible]	[illegible]	[illegible]	[illegible]
1955	[illegible]	[illegible]	[illegible]	[illegible]
1956	[illegible]	[illegible]	[illegible]	[illegible]
1957	43.4	[illegible]	[illegible]	[illegible]
1958	45.8	[illegible]	[illegible]	[illegible]
1959	[illegible]	[illegible]	[illegible]	[illegible]
1960	56.6	[illegible]	[illegible]	[illegible]
1961	58.3	[illegible]	[illegible]	[illegible]
1962	71.1	[illegible]	[illegible]	[illegible]
1963	87.4	[illegible]	[illegible]	[illegible]
1964	119.6	10.6	[illegible]	[illegible]
1965	153.1	14.0	[illegible]	[illegible]
1966	144.5	15.4	[illegible]	[illegible]
1967	163.1	17.2	180.2	[illegible]
1968	215.2	20.8	236.0	[illegible]
1969	222.0	19.5	241.4	[illegible]
1970	205.2	17.7	222.8	[illegible]
1971	229.7	17.2	247.0	[illegible]
1972	264.6	19.0	283.5	[illegible]
1973	305.3	30.8	336.2	[illegible]
1974	N/A	N/A	285.9	-
1975	N/A	N/A	317.6	-
1976	N/A	N/A	281.3	-
1977	N/A	N/A	321.1	-
1978	N/A	N/A	320.7	-
1979	N/A	N/A	344.0	-
1980	N/A	N/A	353.4	

9.1.2.2.1 Domestic producers. The domestic producers of acrylic and modacrylic fibers are listed in Table 9-7. Plant-specific capacity data for 1970 and 1974-1981 are also presented. Minor additions to capacity are evidence of improvements in the efficiency of capital machinery. The only plant closure occurred in June 1975, when Union Carbide discontinued modacrylic fiber production in Charleston, West Virginia. The capital equipment of the plant was dismantled; the capital machinery specific to spinning fibers was scrapped by Union Carbide as no buyer could be found.[24] Union Carbide's plant had an annual capacity of 10 gigagrams (22 million pounds) of fiber, which was consumed in all modacrylic fiber markets and was particularly important in the deep-pile fabrics, drapery, scatter-rug, and hairpiece markets.[25] Union Carbide was never able to generate sufficient demand for this fiber to result in a profitable operation.

Two of the producers, American Cyanamid and Badische Corporation, will not be affected by the proposed NSPS because neither uses a solvent that is a volatile organic compound. American Cyanamid uses an aqueous salt for solvent; Badische Corporation uses zinc chloride.

In 1977, shipments by all domestic producers of acrylic and modacrylic fibers (yarn, staple, tow and waste) were valued at $495.8 million by the Bureau of the Census. Shipments by quantity were estimated to be 336.3 gigagrams (741.4 million pounds). The implied average producer price is therefore $1.48 per kilogram ($0.67 per pound). Shipments of acrylic and modacrylic staple were estimated to have a value of $370.2 million and to total 259.1 gigagrams (571.3 million pounds), for an implied producer price of $1.43 per kilogram ($0.65 per pound). The residual shipments of 77.2 gigagrams (170.2 million pounds), valued at $125.6 million, can be assumed to consist of multifilament yarn, tow, and salable waste. Shipments of monofilament yarn in 1977 were estimated by the Bureau of the Census to be zero; this is consistent with data collected by the Textile Economics Bureau.[26]

The relatively low value-to-weight ratio of the fibers, plus their bulkiness, tends to make shipping cost an important consideration in the purchase decision of a fiber user. As a consequence, a fiber

TABLE 9-7. DOMESTIC PRODUCERS OF ACRYLIC AND MODACRYLIC STAPLE AND TOW AND CAPACITY HISTORY[10,22,23] (gigagrams)

	Began production[a]	Capacity								
		1970[a]	1974[b]	1975[c]	1976[b]	1977[b]	1978[b]	1979[b]	1980[b]	1981[b]
Acrylic fiber producer										
American Cyanamid Co. Pensacola, FL	N/A	45.3	54.4	56.7	56.7	56.7	54.4	56.7	56.7	56.7
Dow Badische Co. Williamsburg, VA	1958	18.1	20.0	31.8	32.7	45.4	31.8	34.0	34.0	31.8
E. I. du Pont de Nemours & Co., Inc. Camden, SC Waynesboro, VA	1950 1945	127	111.1	133.8	140.6	138.3	140.6	142.9	142.9	143.8
Monsanto Co. Decatur, AL	1952	99.8	99.8	106.6	117.9	149.7	147.4	142.9	142.9	142.9
Modacrylic fiber producer										
E. I. du Pont de Nemours & Co., Inc. Camden, SC	1950	---[d]	---[d]	4.5	---[d]	---[d]	---[d]	---[d]	---[d]	---[d]
Eastman Kodak Co. Kingsport, TN	1952	11.3	20.4	18.1	18.1	18.1	18.1	18.1	18.1	18.1
Monsanto Co. Decatur, AL	1952	---[e]	---[e]	11.3	---[e]	---[e]	---[e]	---[e]	---[e]	---[e]
Union Carbide Corp. Charleston, WV	1949	N/A	13.6	closed	closed	closed	closed	closed	closed	closed
Total		J301.5	319.3	362.8	366.0	408.2	392.3	394.6	394.6	393.3

[a] Reference 22.

[b] Reference 23.

[c] Reference 10.

[d] Included in Du Pont's acrylic fiber capacity above.

[e] Included in Monsanto's acrylic fiber capacity above.

producer who is closely located to his customers has a competitive advantage. One would expect, therefore, that fiber producers would locate near fiber-consuming industries, and this appears to be the case. Acrylic and modacrylic fiber producers are concentrated in the southeastern United States, near the center of the domestic textile manufacturing industry.

9.1.2.2.2 Industry structure and capacity. Table 9-8 illustrates the end-use markets that the various producers supplied in 1975, the most current year for which such data are available. All producers compete in the market for textile staple and tow (for both apparel and home furnishings). American Cyanamid and Monsanto are the two competitors in the market for acrylic fiber for carpet. End use of acrylic and modacrylic staple and tow in textile manufacture was approximately 72 percent of all end uses in 1975. Carpet manufacture accounted for about 27 percent of end use.[27]

Many qualitative data indicate that the acrylic and modacrylic staple and tow produced by the various companies are differentiated and have segmented end uses within apparel, home-furnishings, and industrial segments of the market. However, no detailed quantitative data are available to confirm or deny this implication that the fibers produced by the various companies are not substitutable for one another.

All manufacturers of acrylic and modacrylic fibers have captive polymerization facilities. Eastman Kodak and Badische purchase acrylonitrile for polymerization; the other three manufacturers make acrylonitrile. American Cyanamid produces acrylonitrile from purchased propylene and captive ammonia. Monsanto has captive supplies of both propylene and ammonia. Du Pont produces acrylonitrile from captive supplies and supplemental purchases of propylene and ammonia. None of the modacrylic-fiber manufacturers (Du Pont, Eastman, Monsanto) produces its own vinyl chloride or vinylidene chloride comonomers.[28]

American Cyanamid manufactures and sells products in five major areas: agricultural chemicals including fertilizers, pesticides, animal feed, and veterinary products; consumer toiletries, hair preparations, and perfumes; pharmaceuticals; industrial and specialty chemicals; and Formica construction products.[29] American Cyanamid

TABLE 9-8. END-USE MARKET OF ACRYLIC AND MODACRYLIC STAPLE AND TOW BY CAPACITY 1975[10]
(gigagrams)

	Textile	Carpet	Industrial	Total
Acrylic fiber producer				
American Cyanamid Co.	34.0	22.7	F0.5	F57.2
Dow Badische Co.	14.1	18.1	0.5	32.7
E. I. du Pont de Nemours & Co., Inc.	132.9	0	0.9	133.8
Monsanto Co.	51.3	54.4	0.9	106.6
Modacrylic fiber producer				
E. I. du Pont de Nemours & Co., Inc.	4.5	0	0	4.5
Eastman Kodak Co.	13.6	3.6	0.9	18.1
Monsanto Co.	10.9	0	0.5	11.3
Total	261.3	98.8	F4.2	F364.2

does not manufacture textiles from its acrylic fibers, but sells the fibers as an intermediate good (staple and tow forms) to textile manufacturers. The firm does manufacture acrylic sheet and acrylic molding compounds.[30]

Eastman Kodak is the world's largest producer of photographic products, manufacturing amateur and professional films and equipment and related supplies. In addition to synthetic textile fibers (acetate, modacrylic, and polyester), Eastman Kodak produces plastics and chemicals.[31] The company does not manufacture textile products from its fibers.

Du Pont is the largest domestic chemical producer, manufacturing nylon, polyester, acrylic and specialty fibers; chemicals and pigments; elastomers, films, engineering resins and other plastic products; and medical, printing, electronic, explosives and agricultural specialty products.[32] Du Pont produces aramid, nylon, olefin, polyester, spandex and Teflon fibers,[33] which are sold directly to textile producers. The firm also manufactures acrylic finishes and coatings and filled acrylic building products.[34]

Monsanto is the fourth largest producer of chemicals in the United States. Primary products of the company are herbicides, insecticides, nitrogen fertilizers, industrial and specialty chemicals, intermediates, plastics and resins, process controls and electronics, chemical and environmental systems, and nylon and polyester fibers.[35] A producer of acrylonitrile, Monsanto makes ABS and SAN resins as well as acrylic and modacrylic fibers. Manmade fibers generated approximately 17 percent of Monsanto's sales in 1979.[36]

Badische Corporation has been fully owned by BASF-Ag of West Germany since 1978. Prior to that, the company was partly owned by BASF and Dow Chemical, under the name Dow Badische Company.

Table 9-9 indicates the relative importance of fiber sales to each domestically owned producer of acrylic or modacrylic fibers. It is evident from the companies that make acrylic and modacrylic fibers that the industry is a part of the chemical industry. Production of acrylic and modacrylic fibers is closely linked with the production of the polymers and solvents used as inputs. The fiber producers sell to diverse markets, but do not themselves compete in textile, carpet or other end-use markets.

TABLE 9-9. SIGNIFICANCE OF FIBER DIVISIONS TO DOMESTICALLY OWNED ACRYLIC AND MODACRYLIC FIBER PRODUCING FIRMS[37]

	Approximate fiber sales (million dollars)			Corporate sales (million dollars)			Percent fiber to corporate sales		
Company	1977	1978	1979	1977	1978	1979	1977	1978	1979
E. I. du Pont de Nemours and Co., Inc.	3,095	3,444	4,145	9,435	10,584	12,572	32.8	32.5	33.0
Monsanto Co.	884	963	1,069	4,595	5,019	6,193	19.2	19.2	17.3
Eastman Kodak Co.	330	340	360	5,967	7,913	8,028	5.5	4.8	4.5
American Cyanamid Co.	85	88	89	2,444	2,780	3,187	3.5	3.2	2.8

The capacity data for the industry, presented in Table 9-10, indicate a high degree of concentration. There is a small number of firms, and currently more than 70 percent of total capacity is owned by the two largest firms, Du Pont and Monsanto. Further, both the acrylic and modacrylic segments of the industry are dominated by two companies. In the case of acrylics, Du Pont and Monsanto operate more than 70 percent of total capacity; in the case of modacrylics, Eastman Kodak and Monsanto operate more than 85 percent of total capacity.

Table 9-11 provides production and production capacity time-series data for the aggregate domestic acrylic and modacrylic industry. Growth in capacity was rapid in the years 1960-1974; the compound annual average rate of growth was nearly 10 percent, compared to a rate of just less than 1 percent from 1974 to 1980.

Capacity increases were supported by the growth in production from 1960 through 1973, with only minor and temporary setbacks in 1966 and 1970. A drastic decline in production (some 30 percent) occurred over the years 1974 and 1975. Since 1976, production has again increased, although capacity has remained stable. Consequently, by 1980 the operating rate for the industry was approximately 90 percent. The data presented in Table 9-6 indicate that most production growth (and absolute production) has occurred in acrylic rather than modacrylic fibers. All production is in staple and tow forms of fiber; the production of waste fiber (approximately 5 percent) is ancillary.

9.1.2.2.3 Industry performance. Table 9-12 contains annual financial data for the domestically owned producers of acrylic and modacrylic fibers for the years 1977 through 1979. It is evident that net sales for the four companies have kept pace with, and probably exceeded, the rate of inflation over the period. The earnings before interest and taxes of Du Pont and Eastman Kodak have also kept pace with inflation. With the exception of Du Pont, all companies increased their nominal levels of long-term debt over the period; however it is not evident that any firms increased real levels of long-term debt. All four of the companies appear to be financially sound overall. The caveat must be added that these aggregate financial data shed no light on the financial status of the modacrylic- and acrylic-producing

TABLE 9-10. DOMESTIC PRODUCERS OF ACRYLIC AND MODACRYLIC FIBERS RANKED BY CAPACITY, 1975[10]

Company	Rank	Percent of total acrylic and modacrylic capacity	Cumulative percent
E. I. du Pont de Nemours & Co., Inc.	1,2	38.0	36.2
Monsanto Co.	1,2	32.4	70.4
American Cyanamid Co.	3	15.6	86.0
Dow Badische Co.[a]	4	9.0	95.0
Eastman Kodak Co.	5	5.0	100.0

Company	Rank	Percent of acrylic capacity	Cumulative percent
E. I. du Pont de Nemours & Co., Inc.	1	40.6	40.6
Monsanto Co.	2	32.3	72.9
American Cyanamid Co.	3	17.2	90.1
Dow Badische Co.[a]	4	9.9	100.0

Company	Rank	Percent of modacrylic capacity	Cumulative percent
Eastman Kodak Co.	1	53.3	53.3
Monsanto Co.	2	33.3	86.6
E. I. du Pont de Nemours & Co., Inc.	3	13.3	99.9

[a] Dow Badische Co. was a joint venture of Dow Chemical Company (U.S.A.) and BASF Overzee, N.V. In June 1978, the company was sold to BASF-Ag of W. Germany and was later renamed Badische Corp.

TABLE 9-11. PRODUCTION AND PRODUCTION CAPACITY OF ACRYLIC AND MODACRYLIC FIBERS, 1960-1980[12 38 39]

Year	Capacity[a] (gigagrams)	Total production (gigagrams)	Capacity utilization (percent)
1960	93.8	61.5	66
1961	97.4	63.5	65
1962	103.3	77.0	75
1963	119.1	95.0	80
1964	152.7	130.7	86
1965	202.0	166.9	83
1966	228.8	159.9	70
1967	243.7	180.2	74
1968	278.6	236.0	85
1969	292.2	241.5	83
1970	298.5	222.8	75
1971	316.2	247.0	78
1972	341.6	283.5	83
1973	356.5	336.2	94
1974	373.3	285.9	77
1975	374.6	237.6	63
1976	393.7	281.3	71
1977	393.7	321.1	82
1978	391.8	328.7	84
1979	394.1	344.8	87
1980	394.1	353.4	90

[a] November of the year.

TABLE 9-12. FINANCIAL DATA FOR DOMESTICALLY OWNED PRODUCERS OF ACRYLIC AND MODACRYLIC FIBER, 1977-1979[40]
(thousand dollars)

Company		Net sales	Earnings before interest and taxes	Net working capital[a]	Current assets	Current liability	Annual interest expenses	Total assets	Long-term debt	Net tangible worth (equity)
E. I. du Pont de Nemours & Co., Inc.	1979	12,571,800	1,645,900	2,707,900	4,447,300	1,739,400	142,100	8,940,200	1,066,900	5,312,100
	1978	10,584,200	1,474,000	2,349,400	3,908,200	1,558,800	139,000	8,070,300	1,057,900	4,760,400
	1977	9,434,800	1,141,600	1,949,400	3,186,300	1,236,900	169,300	7,430,600	1,235,800	4,317,000
American Cyanamid Co.	1979	3,187,000	323,000	523,655	1,351,489	827,834	63,000	2,826,762	522,572	1,347,167
	1978	2,780,000	296,000	519,315	1,158,271	638,956	50,000	2,526,149	520,184	1,254,507
	1977	2,412,000	270,000	504,462	1,012,712	508,250	47,000	2,222,251	442,420	1,168,891
Monsanto Co.	1979	6,192,600	621,500	1,322,700	2,458,400	1,135,700	123,300	5,539,100	1,202,500	2,781,800
	1978	5,018,700	602,600	1,295,700	2,180,400	884,700	102,800	5,035,700	1,223,500	2,579,400
	1977	4,594,500	555,000	1,080,000	1,735,400	655,400	86,000	4,350,100	1,030,600	2,400,900
Eastman Kodak Co.	1979	8,028,231	1,732,038	2,781,133	4,522,120	1,740,987	24,774	7,554,128	192,540	5,390,603
	1978	7,012,923	1,700,038	2,436,919	3,999,693	1,562,774	18,754	6,801,067	176,758	4,857,681
	1977	5,966,986	1,219,859	1,953,281	3,191,746	1,238,465	18,911	5,904,228	168,157	4,331,308

[a] Net working capital equals current assets minus current liabilities.

divisions of the firms. As shown in Table 9-9, fiber sales by Du Pont and possibly Monsanto do not appear to have declined in real terms, but those of Eastman Kodak and American Cyanamid have. Given the escalating costs of polymer and solvent, this would seem to indicate that these firms are experiencing declining rates of return for fiber production. The outlook for capacity increases without prior improvement in rates of return is bleak.

9.1.2.3 Demand Conditions. The demand for acrylic and modacrylic fibers is driven by the demand for final products that are several processing and marketing steps removed from the production of the fibers themselves. For example, a substantial portion of the demand for acrylic and modacrylic staple and tow comes from the knitting mills of the textile industry. These mills, in turn, respond to consumer demand for sweaters, socks, shirts, etc., as expressed through retail and wholesale apparel markets.

Textile mills often blend acrylic and modacrylic fibers with other types of fibers to make textile yarn. The demand for the fibers is therefore derived from consumer demand for a highly reworked, mixed fiber product. Once spun into yarn, the fiber is woven into cloth to be cut and sewn into apparel, linking final consumer demand with the output of acrylic and modacrylic fibers. The demand for acrylic and modacrylic fiber used in automobile interiors or household carpeting depends on consumer demand for automobiles and home construction.

9.1.2.3.1 Fiber end uses. The Textile Economics Bureau conducts periodic surveys to determine the end uses that support fibers production. The results of the surveys are reported first in the periodical, Textile Organon, and then in more comprehensive form every five years in the Man-Made Fiber Producers' base Book. The most detailed end-use data for acrylic and modacrylic fibers published from the surveys apply to staple and tow shipments. This is expected since staple and tow have accounted for approximately 95 percent of acrylic and modacrylic shipments in recent years.

The end-use data may be further partitioned into three general classes: apparel, household furnishings, and industrial and other consumption. Tables 9-13 to 9-15 present time-series data for acrylic

TABLE 9-13. ACRYLIC AND MODACRYLIC STAPLE AND TOW SHIPMENTS BY APPAREL END USES[41] [42]
(gigagrams)

End use	1968		1969		1970		1971		1972		1973		1974 (Old)[a]		1974 (New)[a]		1975		1976	1977
	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven		
Anklets and socks	9.6		10.6		11.4		9.9		10.6		14.9		17.8		17.8		18.9		95.2	118.8
Sweaters	34.2		27.0		25.7		23.2		26.9		35.6		30.0		30.0		30.2			
Craft yarns	3.1		4.7		11.0		15.3		25.0		33.0		27.5		27.5		38.5			
Pile fabrics--shell	3.4	0.7	6.1	0	5.0	+	7.7	0	9.1	0	12.7	0	12.9	0.1	27.2	0.1	30.1	+	32.8	39.4
Pile fabrics--linings	11.7	0	15.6	0	14.0	0.1	12.0	0.1	14.2	0	14.9	0.1	10.4	0						
Boot liners	0.2		0.2		0.2		0.2		0.2		1.1		1.0							
Other linings	0	0.1	0.2	+	0.1	+	0.0	+	0.1	+	0.1	+	0	+						
Men's underwear and nightwear	0.4	+	0.2	0	0.1	0	0.1	0	0.1	0	0	0	0.1	+	0.1	+	0.1	+	38.4[b]	50.1[b]
Women's underwear and nightwear	1.2	0	1.6	0	2.2	+	2.2	0	4.4	0.5	7.2	0	5.2	+	5.2	0	1.1	0		
Robes and loungewear	+	+	+	+	0	0.1	+	0	+	+	0.4	0	0.2	0	0.2	0	0	0.2		
Men's suits, slacks and coats	0	2.9	0.1	7.7	0.1	6.3	0.5	1.9	1.2	0.9	1.4	0.6	1.1	1.4	Included in top-or bottom-type fabrics below					
Women's suits, slacks and coats	9.6	1.2	9.7	1.6	6.7	1.7	8.7	0.7	12.4	1.1	16.1	2.1	12.9	1.5						
Women's dresses and playsuits	17.7	1.8	22.8	1.4	23.3	1.5	27.9	4.3	30.3	4.4	30.4	3.8	18.2	1.7						
Men's shirts	10.4	0	8.6	0	7.0	+	8.7	0	9.3	0	11.3	0	9.7	+						
Women's blouses and shirts	0.9	0	0.1	0	1.3	0	1.3	0	1.8	0.4	3.2	0	1.4	+						
Other apparel	0.9	1.3	1.5	0.1	1.9	1.3	2.0	0.9	2.9	1.9	3.0	1.4	3.9	+						
Top-type fabrics[c]															25.5	1.0	18.9	0.1		
Bottom-type fabrics[d]															21.7	3.6	10.5	1.8		
Subtotal	103.1	8.1	109.0	10.9	110.0	11.1	119.7	8.1	148.6	9.4	185.3	8.2	152.4	4.8	155.3	4.8	148.2	2.0		
Total	111.2		119.9		121.1		127.8		158.0		193.5		157.2		160.1		150.3		166.3[b]	208.4[b]

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[a] The new 1974 and 1975 figures for pile fabrics include all apparel and home-furnishings applications. Pile fabrics for doll hair, toys, etc., are included in Table 9-15.

[b] Excludes woven apparel in these categories.

[c] Top-type fabrics: Men's, women's and children's top-type fabrics include all shirts, blouses, lightweight dress and lightweight fashion fabrics. The fabrics generally weigh 4.0 ounces or less per square yard.

[d] Bottom-type fabrics: Men's, women's and children's bottom-type fabrics include pants, sportswear, tailored clothing, career apparel and heavier weight fashion fabrics. The fabrics generally weigh more than 4.0 ounces per square yard.

TABLE 9-14. ACRYLIC AND MODACRYLIC STAPLE AND TOW SHIPMENTS BY HOME-FURNISHINGS END USES[41] [42]

(gigagrams)

End use	1968	1969	1970	1971	1972	1973	1974[a]		1975	1976	1977
							Old	New			
Carpets and rugs											
Tufted-transportation	0	0	0	0	0	0	0	0	0		
-Broadloom	67.0	60.3	55.4	61.4	56.6	68.7	47.9	47.9	34.6		
-Scatter/bath	1.4	3.2	2.7	1.6	2.7	3.0	2.0	2.0	1.8		
Knit face	2.6	2.7	2.8	3.0	2.8	3.4	0.5	0.5	0.3		
Woven face	4.1	1.5	1.0	1.3	0.9	1.2	0	0	0		
Needle/punched	1.0	0.2	0.5	0.2	0	0	1.1	1.1	0.8		
Subtotal carpets and rugs	76.1	67.9	62.3	67.5	63.1	76.3	51.6	51.6	37.4	40.2	33.1
Other home furnishings											
Bedspreads and quilts	0.2	0	0	0	0.1	0.2	0	0	+		
Blankets	7.2	6.1	4.2	4.8	10.6	17.8	13.9	13.9	15.4	15.5	22.7
Curtains	0	0	0	0	0	0	+	+	0		
Drapery							2.1	2.1	2.1		
Upholstery and slipcovers	1.4	1.3	1.6	2.4	4.2	5.9	2.8	0.5	0.9		
Other	0	0.2	0.2	0.4	0.6	2.9	1.9	1.3	1.3		
Subtotal other home furnishings[b]	8.9	7.5	6.0	7.6	15.5	26.9	20.7	17.8	19.7		
Total home furnishings	84.9	75.4	68.3	75.2	78.6	103.2	72.2	69.3	57.1	---[c]	---[c]

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[a] The new 1974 and 1975 figures for pile fabrics include all apparel and home-furnishings applications. Pile fabrics for doll hair, toys, etc., are included in Table 9-15.

[b] Other home furnishings include towels and toweling, and woven and lace napery.

[c] Total home furnishings not available due to aggregation of data across end uses in these years.

TABLE 9-15. SHIPMENTS OF ACRYLIC AND MODACRYLIC STAPLE AND TOW BY INDUSTRIAL AND OTHER CONSUMER END USES[43]
(gigagrams)

End use	1968	1969	1970	1971	1972	1973	1974	1975
Flock	0	0	+	+	+	0	0	0
Doll hair, toys, etc.	0.5	1.4	2.1	1.0	0.6	0.9	1.9	1.8
Fiberfill and stuffing	0.1	0.2	0	+	0	0.3	0.1	0.8
Felts	0	0	0	0.1	0.1	0.2	0	+
Filtration	0.2	0.3	0.2	0.2	0.3	0.1	0	+
Bags and bagging	9.2	12.4	0.8	2.4	1.4	0.1	+	+
Coated and protective fabrics	0.2	0.3	0	0.1	0.6	0.4	0	0.1
Other industrial and consumer uses[a]	5.2	4.5	2.4	3.4	3.2	1.2	1.8	1.7
Total	15.4	19.2	5.7	7.1	6.2	3.2	3.9	4.3

[a] Other industrial and other consumer uses include narrow woven fabrics, medical, surgical and sanitary fabrics, transportation upholstery, sewing thread, paper and tape reinforcing, paint roller covers, wiping cloths, tobacco shade cloth, and other.

TABLE 9-16. SHIPMENTS OF ACRYLIC AND MODACRYLIC FIBER WASTE BY END USE[44]
(gigagrams)

End use	1968	1969	1970	1971	1972	1973	1974	1975
Pile fabrics	1.7	1.0	1.4	0.3	0.6	0.3	0	0
Other apparel	0.2	0.9	0.5	0	0	0.2	0.2	0.5
Blankets	1.5	3.1	5.3	6.7	5.3	4.6	4.4	4.8
Needle-punched carpets	1.7	1.0	1.4	0.1	0	0	+	0
Other carpets and rugs	1.5	1.9	1.2	1.6	2.3	2.3	2.1	1.9
Drapery								
Upholstery								
Nonwoven structures	0	0	0	0	0	0	0	0
Filling and stuffing	0	0.2	1.2	1.8	2.2	2.0	1.6	1.8
Rope, cordage and twine								
Other domestic	0	0	0	0	0.1	0	0	0
Total domestic	6.7	8.1	11.0	10.6	10.6	9.5	8.5	9.0
Exports	0.2	1.4	0.3	0	0.2	0	0	0
Total waste	6.9	9.6	11.2	10.6	10.7	9.5	8.5	9.0

and modacrylic staple and tow shipments to various end uses within each of these three classes. In 1975, the last year for which fairly disaggregated end-use data are available, apparel end use accounted for 71 percent of domestic shipments to domestic processors of fiber. Home-furnishings end use accounted for 26 percent of such shipments; the residual was consumed in industrial and other consumer applications. Within the various apparel categories, the largest end uses were estimated to be in craft yarns (25.6 percent), sweaters (20.1 percent), pile fabrics (20.0 percent), anklets and socks (12.6 percent) and top-type fabrics (12.6 percent). Among home-furnishings end uses, most of the fiber shipped in 1975 was used in tufted-face broadloom rugs (61.0 percent) and blankets (26.9 percent). Doll hair, toys, etc., accounted for 40.6 percent of industrial use of acrylic and modacrylic fibers.

These data series illustrate the recent variations and trends in the end use of acrylics and modacrylics. The fluctuations in the shipments to apparel end uses appear to reflect changes in style, such as the popularity of polyester knits in the mid-1970s, and world events, such as the increased use of sweaters associated with the rise in energy prices after 1973. Shipments of acrylic and modacrylic for use in blankets have risen dramatically since 1972-1973, while the use of acrylic and modacrylic in rugs appears to have fallen off since 1968 due to competition from nylon fibers. Data that distinguish between acrylic and modacrylic end use are not available.

Shipments of acrylic and modacrylic waste by end use are presented in Table 9-16. This table shows that over the period 1968-1975, the use of acrylic and modacrylic waste in pile fabrics and needle-punched carpets was phased out, while its use in blankets (over 52 percent of waste shipments in 1975) and filling and stuffing grew considerably.

Time-series data on domestic shipments of acrylic and modacrylic staple, tow, and waste by the three principal classes of end use and exports are presented in Table 9-17. As mentioned previously, the apparel end use dominates acrylic and modacrylic consumption, and most of the remaining shipments are to the home-furnishings industry.

TABLE 9-17. DOMESTIC SHIPMENTS OF ACRYLIC AND MODACRYLIC FIBERS BY END USE[12 38]
(gigagrams)

Year	Staple and tow				Waste				Exports		
	Apparel	Home furnishings	Industrial and other	Total	Apparel	Home furnishings	Industrial and other	Total	Staple and tow	Waste	Total
1960				52.5				0.9			
1961				56.1				0.8			
1962				66.6				0.7			
1963				91.3				1.3	5.1		
1964				119.2				2.3	10.1		
1965				147.0				3.9	9.1	0	9.1
1966				148.6	1.0	2.0	0	3.0	10.4	0.4	10.8
1967	95.2	69.1	3.9	168.2	2.6	4.9	0	7.5	12.8	0	12.8
1968	111.2	85.1	15.4	211.6	1.9	4.8	0	6.7	18.1	0.2	18.3
1969	119.9	75.7	19.2	214.5	1.9	6.1	0.2	8.1	21.8	1.4	23.2
1970	121.1	68.3	5.7	195.1	1.9	7.9	1.2	11.0	24.5	0.3	24.7
1971	127.8	75.2	7.1	210.1	0.3	8.4	1.8	10.6	30.2	0	30.2
1972	158.0	78.6	6.2	242.8	0.6	7.7	2.3	10.6	42.6	0.2	42.8
1973	193.5	103.2	3.2	299.9	0.5	7.0	2.0	9.5	46.3	0	46.3
1974	160.1	69.3	3.9	233.3	0.3	6.5	1.7	8.5	36.2	0	36.2
1975	150.3	57.1	4.3	211.7	0.5	6.7	1.9	9.0	39.1	0	39.1
1976				234.3					49.8		
1977				280.8					41.1		
1978				258.9					68.3		
1979				247.9					101.4		
1980				265.5					84.3		

Acrylic and modacrylic fibers can be blended with other fibers when spun into yarn. Such blending may enhance the characteristics of other fibers as well as substitute for them. As a result, the market role of acrylic and modacrylic fibers relative to other fibers is difficult to establish. Because of the characteristics of acrylics and modacrylics, they appear to compete most directly with natural fibers such as wool or cotton in the sweater, sock and pile-fabric markets. On the basis of end-use data for bottom-type and top-type fabrics, acrylic and modacrylic fibers appear to compete also with natural fibers and polyester. End-use data indicate competition with nylon and polyester fibers in the carpet market. The data presented in Table 9-18 show that the role of acrylics and modacrylics in the staple and tow market declined dramatically relative to that of nylon and polyester between 1960 and 1975.

In summary, the market for acrylic and modacrylic fibers is both diverse and driven by consumer demand several steps removed from actual fiber production. Shipments of acrylic and modacrylic fibers are 95 percent staple and tow, most of which is spun and knit into apparel. Other fibers may either complement or substitute for acrylic or modacrylic staple and tow, depending on the particular fiber and end use considered. While it appears that acrylics and modacrylics have at least maintained their competitive position relative to natural fibers, they have been losing portions of their apparel and home-furnishings market to polyester and nylon. Foreign competition in the acrylic and modacrylic fiber market is indirect, coming principally from imports of finished consumer goods.

9.1.2.3.2 Foreign trade. Exports of acrylic and modacrylic fiber staple and tow have grown faster than domestic consumption. Between 1963 and 1980, annual compound growth in exports was 17.9 percent, as compared with 6.5 percent growth in shipments to domestic processors. Even so, exports of staple and tow accounted for only 24.1 percent of all shipments of acrylic and modacrylic staple and tow in 1980. Exports of waste have been very small or insignificant in recent years.

TABLE 9-18. TOTAL SHIPMENTS OF NONCELLULOSIC STAPLE AND TOW[45]
(gigagrams)

	Producers' shipments								
	Domestic consumption								
Year	Nylon	Acrylic[a]	Polyester	Other	Total	Exports	Total	Imports	Total domestic consumption
1960	12.5	52.5	29.0	1.1	95.2	11.9	107.1	1.1	96.3
1961	16.3	56.1	32.1	1.4	105.9	10.1	116.0	1.4	107.3
1962	21.5	66.6	52.2	1.6	142.0	9.2	151.2	6.3	148.3
1963	24.6	91.3	68.3	2.3	186.4	8.3	194.7	4.0	190.4
1964	30.9	119.2	80.4	3.9	234.5	15.4	249.9	8.7	243.2
1965	38.6	147.0	131.6	6.1	323.2	14.6	337.8	23.6	346.8
1966	49.3	148.6	168.6	15.0	381.4	18.0	399.4	27.6	409.1
1967	54.6	168.2	243.4	18.3	484.5	27.3	511.8	28.6	513.1
1968	71.2	211.6	342.5	23.7	649.1	32.7	681.8	40.7	689.7
1969	91.8	214.5	400.1	28.0	734.4	45.4	779.8	30.6	764.9
1970	91.1	195.1	449.8	26.0	762.0	49.2	811.2	26.1	788.1
1971	149.5	210.1	503.5	26.7	889.7	59.1	948.9	42.3	932.0
1972	215.9	242.8	583.0	28.8	1,070.5	78.9	1,149.4	47.0	1,117.5
1973	265.8	299.9	693.1	31.4	1,290.3	105.5	1,395.9	51.1	1,341.4
1974	221.0	233.3	628.8	27.0	1,110.1	88.5	1,198.6	33.2	1,143.2
1975	252.7	211.7	667.5	24.8	1,156.7	95.1	1,251.8	25.4	1,182.2

[a] Includes modacrylic.

Imports of acrylic and modacrylic fibers, shown in Table 9-19, have generally declined since the early 1970s. In 1980, staple and tow imports were 6.0 gigagrams. Of course, fiber produced abroad is most likely to be imported in the form of finished goods such as imported clothes. Textile Organon refers to "substantial imports of finished products, such as neckties, sweaters, blankets, tablecloths, rugs, hosiery, shirts, suits and dresses, etc., (which) are not included in the (end-use) survey ...."[46]

9.1.2.4 Projections. Projections of growth for the acrylic and modacrylic fibers industry contained in published sources vary considerably. Consequently, with a current industry capacity utilization rate of 90 percent, the various growth projections yield strikingly different results for projecting dates for capacity additions. The following paragraphs summarize the projected growth rates contained in published sources.

Data Resources, Inc., (DRI) in its publication Chemical Review (Winter 1979) forecast quantity of production of acrylic fibers for the years 1982, 1985, 1990 and 1995, with a base year of 1978.[47] The implied average annual growth rates compounded annually are 0.7 percent through 1982, 5.6 percent in the period 1982-1985, 1.8 percent in 1985-1990, and 1.5 percent from 1990 to 1995. The implied average annual growth rate (compounded annually) over the period from the base year to 1990 is 2.3 percent. The capacity shortfalls projected by DRI (assuming maximum capacity utilization of 92 percent) were 25 gigagrams (56 million pounds) in 1985, 63 gigagrams (138 million pounds) in 1990, and 96 gigagrams (211 million pounds) in 1995.

DRI also projected growth in domestic consumption for these same years. The implied average annual growth (compounded annually) for the period 1978 to 1990 is 3.4 percent. The difference in the projected growth rates for domestic consumption and for production are due to projected growth rates for imports, exports, and changes in inventory levels over the period.

As mentioned, 1978 data were the most recent available at the time DRI projected growth rates. The projections are therefore somewhat dated. In contrast with other projections and in light of the general

TABLE 9-19. ACRYLIC AND MODACRYLIC FIBER IMPORTS[12] [38]
(gigagrams)

Year	Staple and tow	Waste	Total
1964	6.5	1.0	7.5
1965	13.0	1.5	14.5
1966	8.8	1.4	10.2
1967	15.8	1.6	17.4
1968	22.3	2.2	24.4
1969	15.6	1.9	17.5
1970	12.0	2.5	14.5
1971	21.8	3.7	25.5
1972	19.3	4.6	23.9
1973	19.4	4.4	23.9
1974	8.8	3.1	11.8
1975	3.8	2.0	5.8
1976	7.5	2.5	10.0
1977	7.4	1.6	8.9
1978	8.2	N/A	N/A
1979	5.9	N/A	N/A
1980	6.0	N/A	N/A

economic conditions of the years 1979 to 1980, the DRI projectons somewhat overstate growth in those years.

Chemical and Engineering News (C&EN) in the December 1, 1980, issue reports that demand for acrylic fibers grew at an average annual rate of 3.8 percent from 1976 to end-of-the-year 1979, and that growth in 1980 was comparable. C&EN reports that some acrylic fiber producers expect growth in demand of 5 percent in 1981. However, some producers are forecasting "long-term growth for acrylic fibers at no more than 1 percent per year."[48] These growth projections are less than satisfactory because they are difficult to interpret. The bases and sources for the projections are not clear, making it difficult to determine their reliability and appropriateness.

Textile Industries in February 1979 forecast rates of growth in domestic mill fiber consumption (domestic shipments plus imports) for cellulosic, noncellulosic and synthetic fibers.[49] The original sources for the data were the Textile Economics Bureau and International Research Associates. Growth in domestic mill consumption of all fibers is projected to result from reduced imports, increased exports and increasing population. For acrylic and modacrylic fibers, the projected average annual rates of growth in domestic mill consumption are 1.9 percent through 1982 and 1.6 percent in the period 1982-1987. These projections do not specifically address projected growth in production; however, the qualitative statement that imports of fiber will most likely decline suggests that these growth rates do not overestimate comcomitant growth in production.

The final published source of data for projected growth in the acrylics and modacrylics fiber industry is the January 1981 issue of Textile Organon.[50] The Organon summarizes a speech by Dr. David K. Barnes of Du Pont that presented Du Pont's forecasts of growth in domestic consumption of various noncellulosic synthetic fibers. Domestic consumption of acrylic fibers was forecast to grow at an average annual rate of 2.7 percent during the period 1979 to 1985. Again, this forecast is not equivalent to a forecast for growth in domestic production because growth or decline in import and export markets is not addressed. However, imports of acrylic and modacrylic fibers have generally declined since the early 1970s, so that it would not appear that projected growth of 2.7 percent in domestic mill consumption would overestimate growth in domestic production.

To supplement these forecasts from published sources, EPA estimated regression equations using time-series data on domestic production of acrylic and modacrylic fibers. These regression equations provided "in-house" projections that were additional indicators of likely growth in domestic production of acrylic and modacrylic fibers. The annual production data used to estimate the regression equations were collected by the Textile Economics Bureau for the years 1960-1979.

The regression equations estimated a relationship between production and time. This relationship was used to estimate production at future points in time. The equations estimated were of two forms. The first estimated the values of a and b in the following equation:

$$\text{production} = a(\text{year}) + b \quad .$$

The second regression equation estimated values of c and d in the following equation:

$$\text{natural log (production)} = c(\text{year}) + d.$$

Both equations are linear equations; the second is identified as "log"-linear, because the equation is estimated given values that are the natural logarithms of the production data.

Because of the cyclical nature of acrylic and modacrylic fiber production, particularly in the years 1973 to 1979, regressions were run on three distinct time intervals of data. The first case included annual production data over the entire period 1960 to 1979. The second and third cases used subsets of the data employed in the first case. The second case employed annual production data from the years 1970 to 1979 only, and the third case used data from 1975 to 1979 only.

The log-linear regression equation projected growth in domestic production of acrylic and modacrylic fibers of 8.7 percent using 1960-1979 production data, 3.5 percent using 1970-1979 data, and 9.0 percent using 1975-1979 data. The growth rate projected using 1970-1979 data was determined to have the best statistical fit to the data. Also, this time interval allows for some adjustments by producers in response to general economic conditions, and captures the effects of the level of maturity of the industry and of market cycles of the industry.

Linear regression equations do not project a constant growth rate as do log-linear regression equations, but rather estimate a discrete growth rate associated with every point in time. Again, the time interval 1970-1979 provided a projection with the best statistical fit to the data. This linear regression of the annual production data for acrylic and modacrylic fibers projected a growth in 1981 of 2.8 percent declining to growth of 2.4 percent in 1987.

It is important to remember that such regression equations are simplistic; they are only projections based on historical trends. The regression equations employed do not explicitly take into account such factors as national economic trends, interfiber competition (substitutability, relative prices), growth or decline in import and export markets, or, specifically in this case, the price effects associated with the rising costs of polymer and solvent inputs. These considerations are, however, reflected in the regression growth rates derived from historical production data to the extent that the historical data reflect these underlying forces that are the more basic determinants of output.

Four of the projections were chosen to construct a range of the likely capacity shortfalls occurring in the acrylic and modacrylic fiber industry in 1987. The four were the Textile Industries projection of 1.9 percent growth through 1982 and 1.6 percent growth in 1983-1987; Du Pont's projection of 2.7 percent growth over the period 1979 to 1985; the range of 2.8 percent growth in 1981 declining to 2.4 percent growth in 1987 projected by in-house linear regression; and the growth rate of 3.5 percent projected by in-house log-linear regression.

Capacity shortfalls for acrylic and modacrylics estimated from growth in the industry projected by Textile Industries are presented below. Growth of 1.9 percent through 1982, and 1.6 percent from 1983 to 1987 was projected. A base production level of 1979 = 344.8 gigagrams was used for the calculations.

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	1.9	351.4	394.6	0
1981	1.9	358.0	394.6	0
1982	1.9	364.8	394.6	0
1983	1.6	370.7	394.6	0
1984	1.6	376.7	396.5	1.9
1985	1.6	382.6	402.7	8.1
1986	1.6	388.7	409.2	14.6
1987	1.6	395.0	415.8	21.2

Estimated production capacity is the larger of 1) the capacity estimated to be in place in 1980 and 2) the capacity required, at a 95 percent capacity utilization rate, by estimated production. The production capacity estimated to be in place in 1980 is 394.6 gigagrams (see Table 9-7). Estimated capacity shortfall is the difference between the estimate of current capacity, and the capacity needed to meet the production estimates at a 95 percent capacity utilization rate, that is, the column "Estimated Production Capacity".

The second published growth projection, from the January 1981 issue of Textile Organon, was a projection of 2.7 percent growth through 1985. Again 1979 was used as the base year, with production of 344.8. (The projection has been extended to 1987 for comparative purposes.)

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	2.7	354.1	394.6	0
1981	2.7	363.7	394.6	0
1982	2.7	373.5	394.6	0
1983	2.7	383.6	403.8	9.2
1984	2.7	393.9	414.6	20.2
1985	2.7	404.6	425.9	31.3
1986	2.7	415.5	437.4	42.8
1987	2.7	426.7	449.2	54.6

Estimated production capacity and estimated capacity shortfall were calculated as described above.

As mentioned, in-house linear and log-linear regressions were estimated to project further estimates of growth in the acrylics and modacrylics market. Both projections were based upon annual production data from 1970-1979. These data are:

Year	Production (gigagrams)
1970	222.8
1971	247.0
1972	283.5
1973	336.2
1974	285.9
1975	237.6
1976	281.3
1977	321.1
1978	328.7
1979	344.8

Two equations were estimated. The first was a direct linear equation and was of the form:

$$\text{prod}_t = \quad + \quad (t)$$

where prod = production estimated in year t
t = year, t = 1970, 1971,...1979
= intercept of fitted line
= slope of fitted line

The coefficients estimated were:*

$$\begin{array}{rcc} \text{prod}_t = & -19395.08000000 & + \; 9.96909091(t) \\ & (7142.500) & (3.617) \end{array}$$

$$R^2 = 0.487$$

This equation was then used to make projections of production for the years 1980-1987.

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	2.9	343.7	394.6	0
1981	2.8	353.7	394.6	0
1982	2.7	363.7	394.6	0
1983	2.7	373.6	394.6	0
1984	2.6	383.6	403.8	9.2
1985	2.5	393.6	414.3	19.7
1986	2.5	403.5	424.7	30.1
1987	2.4	413.5	435.3	40.7

---

*The standard error for each estimated value is provided in parentheses beneath each estimated value.

Estimated production is obtained by substituting the value of the year in the regression equation obtained from historical data. For example, substituting t = 1980 into the direct linear equation for acrylic and modacrylic fiber yields:

$$prod_t = -15535.26 + [illegible] (1980)$$

$$prod_t = 365.7$$

Estimated production capacity and estimated capacity shortfall were calculated as described above.

The second equation estimated was log-linear and was of the form:

$$\ln(prod_t) = \quad + \quad (t)$$

All definitions from above hold. The coefficients estimated were:*

$$\ln(prod_t) = \underset{(25.424)}{-64.1496146l} + \underset{(0.013)}{0.03636337}(t)$$

$$R^2 = 0.488$$

This equation was used to project production levels of:

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	3.5	347.3	394.6	0
1981	3.5	359.7	394.6	0
1982	3.5	372.7	394.6	0
1983	3.5	386.1	406.4	11.8
1984	3.5	400.0	421.1	26.5
1985	3.5	414.4	436.2	41.6
1986	3.5	429.3	451.9	57.3
1987	3.5	444.8	468.2	73.6

Estimated production is obtained by substituting the value of the year in the regression equation obtaned from historical data. For example, substituting t = 1980 into the log-linear equation for acrylic and modacrylic fiber yields:

$$\log(prod_t) = -64.1496146l + 0.0363633 7 (t)$$

---

*The standard error for each estimated value is provided in parentheses beneath each estimated value.

$$\log(\text{prod}_t) = 5.85005799$$

$$\text{prod}_t = 347.3$$

Estimated production capacity and estimated capacity shortfall were calculated as described above.

Table 9-20 presents the range of projected capacity shortfalls in 1987. The range was constructed from the highest and the lowest estimates of the four estimates for capacity shortfall presented above. Two assumptions are included in these calculations. They are:

(1) Any capacity shortfall before 1982 will be met by debottlenecking existing capacity or by constructing new capacity prior to 1982 (the first year that the NSPS will be in effect). Thus, only the capacity shortfall occurring in the years 1982-1987 will support new capacity in 1982-1987.

(2) Because all the model plants are capable of producing modacrylics, it is assumed that all new capacity built will have the configuration of Model Plant 2, as Model Plant 2 is the least costly of the three plants (see Section 9.2.2.2).

9.1.3 Acetate and Triacetate Fibers

9.1.3.1 Production

9.1.3.1.1 Product description. All cellulosic fibers (acetate, diacetate, triacetate, and rayon) are composed of cellulose acetate, produced by combining cellulose with acetate from acetic acid and acetic anhydride. This process is called acetylation. The cellulosics are differentiated by the percentage of hydroxyl groups that are acetylated in the cellulose molecule. According to the U.S. Federal Trade Commission classification, rayon has less than 15 percent acetylation, cellulose acetate or diacetate has 15 to 92 percent acetylation, and cellulose triacetate has not less than 92 percent acetylation.[9]

9.1.3.1.2 Production technology. Complete acetylation of cellulose is the first step in the production of both acetate and triacetate.* Cellulose acetate for textile fiber production is obtained by controlled partial hydrolysis of cellulose triacetate. The cellulose acetate or

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*Throughout this chapter the term acetate refers to both acetate and diacetate fibers.

TABLE 9-20. ACRYLIC AND MODACRYLIC CAPACITY SHORTFALLS OVER 1982-1987

Fiber Type	Projection	1982 Estimated Production (gigagrams)	1982 Estimated Capacity (gigagrams)	1987 Estimated Production (gigagrams)	1987 Estimated Capacity (gigagrams)	1982-1987 Capacity Shortfall (gigagrams)
Acrylics and Modacrylics Model Plant 2	high (log-linear)	372.7	394.6	444.8	468.2	73.6
	low (Textile Industries)	364.8	394.6	395.0	415.8	21.2

triacetate polymer is then usually dissolved in a solvent for extrusion. Fiber is produced by dry spinning, in which the filaments are extruded into a column of hot inert gas. As the filaments dry, the acetone solvent evaporates, leaving a fiber of almost pure cellulose acetate or triacetate. After spinning, treatment of the fiber varies with the end use anticipated. Acetate yarn is lubricated and wound onto a bobbin as continuous filament yarn with no further treatment. Cigarette filtration tow (cellulose acetate) is lubricated, crimped and dried.

9.1.3.1.3 Production history. Cellulose acetate fibers were first produced commercially in the United States in 1924 by the Celanese Corporation. The fabric woven from these fibers is characterized by drapability, softness, and shrink and mildew resistance. The fabrics are sold both as end products and for manufacture into top-type and bottom-type apparel, lingerie, linings, draperies, and upholstery. The alternate primary use of cellulose acetate fibers is cigarette filtration tow.

Cellulose triacetate fibers were first produced in the United States in 1954, also by Celanese Corporation. The fibers contain a higher ratio of acetate to cellulose than do acetate fibers. Fabrics woven from these fibers are characterized by shrink and wrinkle resistance and pleat retention. The fabrics are marketed both as end products and as inputs to dress, skirt, and sportswear manufacture.

9.1.3.1.4 Role in U.S. economy. The shares of GNP, employment, and new capital expenditures contributed by the cellulose acetate and triacetate fibers industry provide measures of the significance of the industry in the national economy. The most recent industry data available to calculate these shares are contained in the 1977 Census of Manufactures. Data from this source are not disaggregated for the acetate and triacetate industry, but grouped with the rayon industry. This larger industry is defined as SIC 2823, Cellulosic Manmade Fibers.

The cellulosic fibers industry contributed 0.04 of 1 percent to total GNP and 0.02 of 1 percent to total employment in 1977. Of the expenditures on new plant and equipment by all industries that year the cellulosics fiber industry accounted for 0.02 of 1 percent.

Like acrylic and modacrylic fibers, cellulosic fibers are intermediate goods. They consume output of the wood pulp and petrochemical industry and are used as inputs to the textile and cigarette industries. To the extent that these fibers are major consumers of particular petrochemicals, or have poor substitutes in their alternative end-use applications, they may be a critical factor in the economic health of other industries. This is most probable in the cigarette filtration tow application of the fibers.

9.1.3.1.5 Factors of production. The principal materials used to produce acetate and triacetate fibers are wood or cotton linters pulp, acetic acid, acetic anhydride and acetone. The cellulose pulp used for polymer production must be of high purity and have an alpha cellulose content of approximately 94 percent. Wood pulp is less expensive than cotton linters pulp and is currently preferred by acetate and triacetate fiber producers. Domestic sources of wood pulp are ITT Rayonier, Inc., International Paper, Buckeye Cellulose, and Weyerhaeuser Company. Some wood pulp is imported for acetate manufacture.[51] The solvent currently used by the industry is acetone, but other solvents such as a chlorinated hydrocarbon are also compatible with the process.

The major producers of acetate and triacetate, Celanese Corporation and Eastman Kodak, have captive sources of acetic acid. All producers have captive sources of acetic anhydride. Eastman Kodak also has a captive source of acetone.[51] The principal feedstocks, wood pulp and acetone, appear to have a variety of alternative uses. This makes a more competitive and observable market for inputs than was the case for acrylic and modacrylic fibers production.

Acetone is of particular interest because it is the volatile organic chemical (VOC) that the proposed standards aim to control. It is a petrochemical produced both as a coproduct with phenol and by dehydrogenation of isopropyl alcohol. The market for phenol determines the output of acetone as a coproduct. In general, acetone capacity has been underutilized in recent years and this, in conjunction with the possible entry of new competitors to acetone as a methyl methacrylate feedstock, seems to insure ready supplies of acetone in the near to intermediate future.[52]

Acetate and triacetate fibers producers integrate the acetylation step with fiber spinning and product finishing. The technology is well understood and both it and the equipment can be readily purchased.

The other principal purchased inputs to the production of acetate and triacetate fibers are labor and equipment. The majority of the five plants currently producing these fibers were built in the 1930s and 1940s.[53] The production of these fibers is said to be mature. Productivity is being increased by debottlenecking but no major changes in the technology itself, or in the ratio of process inputs, is foreseen. Increased solvent recovery, whether due to the proposed standards or to economic considerations, may be the most dramatic instance of factor substitution considered by producers. A fundamental limitation on factor substitution is the technically fixed ratio of cellulose acetate polymer to polymer fibers; the polymer already accounts for the bulk of production costs.

9.1.3.2 Supply Conditions.

9.1.3.2.1 Domestic producers. The domestic acetate and triacetate fiber producers and their production capacities are listed in Table 9-21. Three companies produce fibers at five plant locations: Celanese Corporation (with three plants), Eastman Kodak, and Avtex Fibers, Inc. Two acetate plants were closed in the mid-1970s; Du Pont closed a 22.6 gigagram-per-year plant in Waynesboro, Virginia, and Celanese Corporation closed a 13.6 gigagram-per-year plant in Rome, Georgia. Both plants produced cellulose acetate yarn.

In 1980, cellulose acetate and triacetate fibers in all forms ranged from \$2.40 to \$2.98 per kilogram, or \$1.09 to \$1.35 per pound (see Section 9.2.3.4). Given the bulkiness of the output, this is a relatively low value-to-weight ratio. As would be expected, fiber producers are located relatively close to their customers in order to minimize transport costs and thereby enhance their competitiveness. Like acrylic and modacrylic producers, acetate and triacetate fiber producers are clustered in the southeastern United States.

Production of acetate and triacetate fibers in the United States from 1960 to 1980 is shown in Table 9-22. At the beginning of this period, yarn accounted for 58 percent of output of the acetate fibers

TABLE 9-21. DOMESTIC PRODUCERS OF CELLULOSE ACETATE AND TRIACETATE FIBERS, 1980[54] [55]

Company	Products	Trade name	Annual capacity (gigagrams)[a] Textile yarn, staple and tow	Annual capacity (gigagrams)[a] Cigarette filtration tow	Annual capacity (gigagrams)[a] Total plant capacity
Celanese Corp.					
Celanese Fibers Co., div.					
Cumberland, MD	Acetate and tow Triacetate yarn, staple and tow	Celanese® Arnel®	32 (70)	--	32 (70)
Parisburg, VA	Acetate yarn, staple and tow, cigarette filtration tow	Celanese®	38 (83)	50[b] (110)	88 (193)
Rock Hill, SC	Acetate yarn, staple and tow Triacetate yarn, staple and tow	Celanese® Arnel®	36 (80)	--	36 (80)
Total (Celanese)			106 (233)	50[b] (110)	156 (343)
Eastman Kodak Co.					
Eastman Chemical Products, Inc., subsid. Tennessee Eastman Co.					
Kingsport, TN	Cigarette filtration tow and acetate yarn	Estron® Chromspun®	25 (55)	95[b] (210)	120 (265)
Avtex Fibers, Inc.	Acetate yarn	Avisco®	20 (45)	--	20 (45)
Total annual capacity for industry			151 (333)	145[b] (320)	296 (653)

[a] Numbers in parentheses are in million pounds.

[b] Estimates as of mid-1976; 1978 production was 331 million pounds, or 11 million pounds greater than 1976 industry capacity.

TABLE 9-22. DOMESTIC PRODUCTION OF CELLULOSE ACETATE AND TRIACETATE4 12 56 57 58

	Textile fiber[a]						Cigarette filtration tow[a]		Total production	
	Acetate yarn		Acetate staple and tow[b]		Total					
Year	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)
1960	103.4	228.2	27.2	60.0	130.6	288.2	48.9	108	179.5	396.2
1961	112.8	249.0	24.0	53.0	136.8	302.0	53.0	117	189.8	419.0
1962	138.5	305.7	20.8	46.0	159.3	351.7	58.0	128	217.3	479.7
1963	140.2	309.5	27.2	60.0	167.4	369.5	59.8	132	227.2	501.5
1964	165.8	365.9	27.2	60.0	192.9	425.9	69.8	154	262.7	579.9
1965	177.2	391.2	24.5	54.0	201.7	445.2	70.7	156	272.3	601.2
1966	178.6	394.3	27.2	60.0	205.8	454.3	69.3	153	275.1	607.3
1967	192.8	425.6	22.7	50.0	215.4	475.6	71.6	158	287.0	633.6
1968	199.3	439.9	22.7	50.0	221.9	489.9	72.9	161	294.9	650.9
1969	206.2	455.2	19.5	43.0	225.7	498.2	77.0	170	302.7	668.2
1970	209.8	463.2	15.9	35.0	225.7	498.2	83.8	185	309.5	683.2
1971	203.5	449.3	12.0	26.5	215.5	475.8	93.8	207	309.3	682.8
1972	181.8	401.4	12.7	28.0	194.5	429.4	101.9	225	296.4	654.4
1973	198.1	437.2	11.3	25.0	209.4	462.2	116.0	256	325.3	718.2
1974	163.8	361.6	9.1	20.0	172.9	381.6	123.7	273	296.5	654.6
1975	136.5[c]	301.3[c]	5.4[c]	12.0[c]	141.9[c]	313.3[c]	130.0[d]	287[d]	271.9	600.3
1976	130.0[c]	286.9[c]	5.0[c]	11.0[c]	134.9[c]	297.9[c]	136.8[d]	302[d]	271.8	599.9
1977	127.7[c]	282.0[c]	3.6[c]	8.0[c]	131.4[c]	290.0[c]	143.6[d]	317[d]	275.3	607.0
1978	136.3[c]	300.9[c]	3.2[c]	7.0[c]	139.5[c]	307.9[c]	149.9[d]	331[d]	289.4	638.9
1979	143.4[e]	316.6[e]	3.2[e]	7.0[e]	146.6[e]	323.6[e]	165.3[f]	364[f]	311.9	687.6
1980	139.9	308.5[e]	N/A	N/A	-	-	N/A	N/A	-	-

[a] Reference 56

[b] Does not include cigarette filtration tow; does include diacetate and triacetate.

[c] Reference 57

[d] Reference 58

[e] Reference 12

[f] Reference 4

industry. Staple and tow accounted for 42 percent of the output, with approximately 15 percent going to the textile market and 27 percent going to cigarette filtration tow. From 1960 to 1970 yarn production grew fairly steadily at an average annually compounded rate of approximately 7 percent. In the early and mid 1970s, yarn production went into a severe slump; production declined every year until 1978 and 1979. Yarn production in 1979 was only 38 percent greater than in 1960, and production again fell in 1980. Production of staple and tow for textile fibers fell steadily, comprising only 0.1 of 1 percent of total acetate and triacetate production in 1979. Production of cigarette filtration tow, on the other hand, increased dramatically over the period 1960 to 1979 (6.6 percent average annually compounded growth), constituting nearly 53 percent of total output of cellulose acetate and triacetate fibers in 1979. Total output has increased at an average annual rate of 3.0 percent per year.

The role of U.S. acetate and triacetate textile fiber in world production is substantial. As shown in Table 9-23, the United States produced over 42 percent of world acetate and triacetate textile fiber in 1978. While this is a slight decline in the percentage of world production from the early years of the decade (46 to 50 percent), it does not appear to represent a direct loss of the U.S. share of the world market since such a small quantity of this yarn is exported from the United States and imports of foreign fiber are negligible. Table 9-23 also shows, however, that U.S. capacity was expected to fall below 40 percent of world capacity in 1980. The declining share of the United States in world production of textile yarn may ultimately result in more indirect if not direct world competition for domestic acetate and triacetate fiber producers.

U.S. production of cigarette filtration tow has had a larger and more stable role in the world market than acetate yarn production. As shown in Table 9-24, the United States accounted for 51 percent of world cigarette filtration tow production in 1978. The world/U.S. interface in this market is particularly critical because so much of U.S. produced filtration tow is exported, and because cigarette exports themselves are a substantial and growing market for U.S. producers.

TABLE 9-23. PRODUCTION AND PRODUCING CAPACITY OF ACETATE AND TRIACETATE TEXTILE FIBER[59]

(gigagrams)

	United States	World
Production		
1972	182	377
1973	198	399
1974	164	359
1975	137	316
1976	130	309
1977	128	310
1978	137	324
Producing capacity		
1979	148	359
1980	148	371

TABLE 9-24. PRODUCTION OF CIGARETTE FILTRATION TOW[60]

(gigagrams)

	1971	1972	1973	1974	1975	1976	1977	1978
Europe[a]	38	43	45	48	49	58	67	73
United States	94	102	116	124	130	137	144	150
Other American[b]	18	19	22	25	26	27	27	31
Asia[c]	23	26	28	30	36	37	39	40
Total	173	190	211	227	241	259	277	294

[a] Belgium, West Germany and United Kingdom

[b] Brazil, Canada, Columbia, Mexico and Venezuela

[c] Japan and South Korea

9.1.3.2.2 Industry structure and capacity. The production of cellulose acetate and triacetate is very concentrated; the largest firm (Celanese Corporation) controls 52.5 percent of the total acetate and triacetate capacity. Celanese and Eastman Kodak together control over 93 percent of the total capacity, with the remaining 6.9 percent belonging to Avtex. Distinguishing between textile yarn and cigarette tow increases the degree of market concentration: Celanese owns 70 percent of textile acetate and triacetate yarn and staple capacity, and Eastman Kodak owns 66 percent of cigarette tow capacity. Qualitative data suggest that the producers of cellulose acetate and triacetate fiber do not compete directly with one another because each has expanded into distinct end-use markets; each producer determines the market practices for the major end-use categories that it dominates.[61] The degree of industry concentration suggests weak local competition as well.

Aggregate production capacity for the textile fiber portion of the acetate and triacetate industry is shown in Table 9-25. These capacity figures reflect the trends in production discussed above and reflect a recent estimate of capacity decline (1979 to 1980). While these figures are only for textile fiber capacity, they show considerable annual variation and suggest that marginal adjustments in capacity are relatively easy. A comparision of these capacity figures with the corresponding production figures in Table 9-22 shows that in 1979 capacity utilization was approximately 90 percent. Historical data for this industry indicate, however, that this rate does not imply capacity expansion.

Cigarette filtration tow capacity data were not available as a time series. The production series, in conjunction with recent firm data and contacts with the industry, suggest that this capacity has been expanding steadily due to debottlenecking and conversion of equipment from cellulose acetate yarn.

9.1.3.2.3 Industry performance. Table 9-26 provides financial data for the years 1977 through 1979 for the publically owned producers of cellulose acetate and triacetate fibers. It is evident that net sales and earnings before interest and taxes have at least maintained

TABLE 9-25. DOMESTIC ACETATE AND TRIACETATE TEXTILE FIBER PRODUCTION CAPACITY[12 57 62]

Year	Continuous filament yarn		Staple and tow		Total	
	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)
1950	149.2	329	51.7	114	200.9	443
1951	169.6	374	64.9	143	234.5	517
1952	173.7	383	70.3	155	244.0	538
1953	175.1	386	73.5	162	248.6	548
1954	173.7	383	77.6	171	251.3	554
1955	138.3	305	75.8	167	214.1	472
1956	132.0	291	52.6	116	184.6	407
1957	132.5	292	40.8	90	173.3	382
1958	139.7	308	39.9	88	179.6	396
1959	137.0	302	39.5	87	176.4	389
1960	144.4	318	41.7	92	186.0	410
1961	143.8	317	41.7	92	185.5	409
1962	147.0	324	41.7	92	188.7	416
1963	157.4	347	37.2	82	194.6	429
1964	175.5	387	31.8	70	207.3	457
1965	200.5	442	31.8	70	232.2	512
1966	209.1	461	27.2	60	236.3	521
1967	205.0	452	27.2	60	232.2	512
1968	215.9	476	22.7	50	238.6	526
1969	223.6	493	22.7	50	246.3	543
1970	224.1	494	18.1	40	242.2	534
1971	222.3	490	14.1	31	236.3	521
1972	220.4	486	14.1	31	234.5	517
1973	214.6	473	12.7	28	227.3	501
1974	203.7	449	12.7	28	216.4	477
1975	174.2	384	8.2	18	182.3	402
1976	181.0[a]	399[a]	8.2[a]	18[a]	189.1	417[a]
1977	142.9[a]	315[a]	3.6[a]	8[a]	146.5	323[a]
1978	149.7[a]	330[a]	3.6[a]	8[a]	153.3	338[a]
1979					164.7	363[b]
1980					151.0	333[b]

Notes: Data do not include cigarette filtration tow.
Data are the actual production capacities in November of each year, projected to an annual rate based on 51 weeks of operation.

[a] Reference 57

[b] Reference 12

TABLE 9-26. FINANCIAL DATA FOR DOMESTIC PRODUCERS OF CELLULOSE ACETATE AND TRIACETATE FIBERS, 1977-1979[40]
(thousand dollars)

Company	Net sales	Earnings before interest and taxes	Net working capital[a]	Current assets	Current liabilities	Annual interest expense	Total assets	Long-term debt	Net tangible worth (equity)
Celanese Corp.									
1979	3,146,000	285,000	455,000	1,055,000	600,000	51,000	2,380,000	512,000	1,039,000
1978	2,609,000	272,000	431,000	866,000	435,000	48,000	2,158,000	552,000	946,000
1977	2,320,000	182,000	373,000	753,000	380,000	44,000	2,010,000	537,000	828,000
Eastman Kodak Co.									
1979	8,028,231	1,732,038	2,781,133	4,522,120	1,740,987	24,774	7,554,128	192,540	5,390,603
1978	7,012,923	1,700,038	2,436,919	3,999,693	1,562,774	18,754	6,801,067	176,758	4,857,681
1977	5,966,986	1,219,859	1,953,281	3,191,746	1,238,465	18,911	5,904,228	168,157	4,331,308

[a] Net working capital equals current assets minus current liabilities.

Note: Financial data were not available for Avtex Fibers, Inc., as the firm is privately owned and does not publish financial information.

TABLE 9-27. SIGNIFICANCE OF FIBER DIVISIONS TO CELLULOSE ACETATE AND TRIACETATE FIBER PRODUCING FIRMS[37]

	Approximate fiber sales (million dollars)			Corporate sales (million dollars)			Percent fiber to corporate sales		
Company	1979	1978	1977	1979	1978	1977	1979	1978	1977
Celanese Corp.	1,719	1,479	1,306	3,146	2,609	2,230	54.6	56.7	56.3
Eastman Kodak Co.	360	340	330	8,028	7,913	5,967	4.5	4.8	5.5
Avtex Fibers, Inc.	300	290	280	300	290	280	100.0	100.0	100.0

pace with, if not exceeded, the rate of inflation over this period. Celanese reduced its nominal (and real) amount of long-term debt over these years; Eastman Kodak increased its nominal debt, but its real level of debt apparently fell. Both companies appear to be financially sound. However, aggregate firm data such as these indicate little about the profitability of the fiber divisions within these companies. Net sales data for these companies and for Avtex Fibers are presented in Table 9-27. It appears that only Celanese has increased its fiber sales in real terms. Fiber sales by both Eastman Kodak and Avtex over this period are negative when netted of inflation. Given the escalating prices evidenced for polymer and solvent, it would appear that at least Eastman Kodak and Avtex Fibers (and possibly Celanese) have been experiencing declining rates of return in their fibers divisions. Avtex' position over this period appears to be especially difficult because 100 percent of its sales are due to fiber production.

These data on aggregate fiber sales indicate little about the profitability of cellulose acetate and triacetate fiber production. However, the data do suggest that manmade fiber manufacturing in general has not been earning rates of return that would suggest capacity additions without cost reductions or price increases.

9.1.3.3 Demand Conditions. The demand for acetate and triacetate fibers, like that for acrylic and modacrylic fibers, is driven by a wide variety of end uses. Consequently, the complex set of complementarity and substitutability relationships at both final and intermediate points of production affect demand. This is perhaps particularly true of acetate and triacetate fibers because of the role of the cigarette industry as a principal consumer of these fibers.

9.1.3.3.1 Fiber end uses. Table 9-28 presents time-series data of general end-use categories for the shipments of acetate and triacetate textile yarn. From 1964 to 1975, apparel end use was the dominant general category (86 percent of shipments to domestic consumers in 1975). Use in home-furnishings was modest (12.7 percent); industrial and other end uses accounted for the residual (1.3 percent).

A more detailed array of end uses for 1968-1975 is presented in Tables 9-29 and 9-30. Within the apparel end uses, underwear and

TABLE 9-28. CONSUMPTION BY END-USE MARKET OF ACETATE YARN[63] [64]

	Apparel		Home furnishings		Industrial		Undistributed	
	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)
1964	124.8	275.6	29.0	64.0	6.0	13.3	4.9	10.8
1965	124.6	274.7	30.1	66.3	6.6	14.6	4.8	10.7
1966	137.8	304.3	26.0	57.4	7.1	15.6	4.7	10.3
1967	161.5	356.6	22.5	49.6	5.7	12.6	1.0	2.1
1968	167.8	370.4	20.7	45.7	4.1	9.1	0.5	1.2
1969	168.7	372.5	27.1	59.9	4.6	10.1	1.0	2.2
1970	179.4	396.1	19.8	43.7	2.3	5.0	0	0
1971	172.0	379.6	21.9	48.4	1.9	4.3	0	0
1972	151.4	334.2	21.8	48.1	1.6	3.6	0	0
1973	153.9	339.7	22.5	49.6	1.4	3.0	0	0
1974	122.5	270.5	21.1	46.5	1.5	3.3	0	0
1975	114.6	252.9	16.9	37.4	1.5	3.4	0	0

TABLE 9-29. ACETATE YARN SHIPMENTS BY APPAREL END USES[65]
(gigagrams)

End use	1968		1969		1970		1971		1972		1973		1974 (Old)[a]		1974 (New)[a]		1975	
	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven	Knit	Woven
Women's anklets and socks	+		0		0		0		0		0		0		0		0	
Sweaters	+		4.1		1.4		1.1		0		0		0		0		0	
Men's underwear and nightwear	31.5	0	28.3	0	24.2	0	20.3	0.2	26.4	0.9	25.4	1.0	0.4	0	0.4	0	+	
Women's underwear and nightwear													22.5	0.2	22.5	0.2	13.3	0.1
Bras and foundations	1.5	2.2	1.4	2.0	1.0	1.6	1.1	0.9	0.4	1.0	0.4	0.7	0.2	0	0.2	0		
Robes and loungewear	4.6	0	7.0	0.5	12.5	0.4	12.9	0.4	13.8	1.4	15.2	1.4	15.2	1.4	15.2	1.4	14.2	0
Lining-type fabrics	1.1	23.7	1.0	26.2	0.1	30.9	0.9	31.1	0.2	29.1	0.4	30.9	0.5	27.8	0.5	27.8	4.8	28.2
Tricot fabric for laminating	30.5		28.8		30.3		20.8		4.6		1.4		1.0		1.0			
Apparel lace	1.2		0.9		0.6		0.7		0.6		0.4		0.8		0.8			
Narrow woven braids		0.5		0.7		0.7		0.8		2.6		2.8		2.1		2.1		1.4
Women's suits, slacks and coats	1.0	4.1	1.0	4.3	6.7	3.1	6.9	2.1	3.8	1.0	3.7	0.9	4.6	0	Included in top- or bottom-type fabrics below			
Women's dresses and playsuits	25.4	31.8	22.2	30.2	31.5	21.0	42.2	16.7	33.3	15.7	37.6	15.2	19.4	8.9				
Swimwear	0.8	1.0	0.8	0.7	0.7	0.4	0.7	0.1	0.5	0	0.4	0	0.3	0				
Shirts and blouses	1.5	4.0	1.5	4.4	1.6	5.4	6.2	3.1	10.6	3.5	10.5	3.7	12.5	2.3				
Other apparel	+	1.6	1.2	2.5	2.0	2.9	1.4	1.5	0.2	2.0	0.1	2.1	0	2.3	0	2.3	0	2.6
Top-type fabrics[b]															32.6	11.2	42.4	3.4
Bottom-type fabrics[c]															4.1	0	2.8	2.7
Subtotal	99.2	69.3	98.3	71.5	113.1	66.6	115.3	56.9	94.5	57.1	95.6	58.5	77.6	45.1	77.6	45.1	77.6	37.0
Total	168.5		169.8		179.7		172.2		151.6		154.1		122.7		122.7		114.7	

[a] The new 1974 and 1975 figures for pile fabrics include all apparel and home-furnishings applications.

[b] Top-type fabrics: Men's, women's and children's top-type fabrics include all shirts, blouses, lightweight dress and lightweight fashion fabrics. The fabrics generally weigh 4.0 ounces or less per square yard.

[c] Bottom-type fabrics: Men's, women's and children's bottom-type fabrics include pants, sportswear, tailored clothing, career apparel and heavier weight fashion fabrics. The fabrics generally weigh more than 4.0 ounces per square yard.

TABLE 9-30 ACETATE YARN SHIPMENTS BY HOME-FURNISHING AND INDUSTRIAN END USES[65, 66]

End use	1968	1969	1970	1971	1972	1973	1974	1975
Home furnishings								
Carpets and rugs	0.1	0.4	+	0	0	0	0	0
Bedspreads and quilts	2.6	2.9	2.9	3.8	5.1	5.9	5.6	7.2
Sheets and other bedding	+	0.5	0.4	0.4	0.2	0	0	0
Curtains	0.8	1.4	1.4	1.8	2.6	3.3	2.7	1.6
Drapery and casements	16.0	20.2	13.5	14.6	13.2	10.8	9.9	6.2
Upholstery and slipcovers						1.4	1.4	1.9
Other home furnishings	1.2	1.6	1.5	1.4	0.7	1.1	1.5	
Total home furnishings	20.7	27.1	19.8	22.0	21.8	22.5	21.1	17.0
Industrial and other consumer uses								
Electrical applications	0.2	0.3	0.3	0.3	0.3	0.2	0.0	+
Paper and tape reinforcing	1.0	1.1	0.4	0.6	0.5	0.2	0.4	0.1
Other industrial and consumer	3.0	3.4	1.5	1.0	0.9	1.0	1.1	1.4
Total industrial and other consumer uses	4.2	4.8	2.3	2.0	1.6	1.4	1.5	1.5

nightwear, and bras and foundations, have been rapidly declining sources of demand. Shipments of top-type fabrics and bottom-type fabrics also decreased over this period.

Cigarette filtration tow production for 1960-79 is presented in Table 9-31. Over the period from 1960 to 1975, shipments to U.S. manufacturers grew at an average annually compounded rate of approximately 5 percent. The most interesting aspect of filtration tow end use is the rapidly growing role of exports both absolutely and relative to U.S. production.

9.1.3.3.2 Foreign trade. Data for export shipments of acetate and triacetate textile yarn are contained in Table 9-32. Export shipments have far exceeded domestic industrial end use, yet accounted for just over 10 percent of total production in 1980.

As mentioned, exports of cigarette filtration tow have grown rapidly, averaging 14 percent compounded annually over the period 1960-1975.

9.1.3.4 Projections. Projections of growth for cellulose acetate and triacetate fibers were found in two publications, the Chemical Economics Handbook and Textile Industries. The Chemical Economics Handbook (SRI International) contains growth projections published in November 1976. Consumption of all cellulose acetate fibers, both for textile use and for cigarette filtration tow, were projected to decline an average of 0.3 percent per year over the period 1975-1981.[73]

SRI also provided distinct projections for the two types of acetate fibers. Consumption of cellulose acetate and triacetate textile fibers was projected to decline at an average annual rate of 3.5 percent over the period 1975 to 1981.[74] Imports and exports of these fibers do not constitute significant markets; exports of acetate yarn accounted for just over 10 percent of total production of acetate yarn in 1980 (see Table 9-32). Data for imports of acetate yarn are not available disaggregated from data for imports of acetate and rayon yarn; however in 1978 imports of these two fibers together were only 12.5 gigagrams.[58] The projected growth rate for domestic consumption is therefore applicable without much error to growth in production.

TABLE 9-31. EXPORTS OF CELLULOSE ACETATE FILTRATION TOW [58] [67] [68] [69]
(gigagrams)

Year	Production[a] United States	Production[a] World	U.S. exports[b]	Exports as percent of total U.S. production
1960	49	56	7	14
1961	53	64	9	17
1962	58	74	12	21
1963	60	82	12	20
1964	70	100	22	31
1965	71	109	22	31
1966	69	118	19	28
1967	72	123	20	28
1968	73	128	24	33
1969	77	136	27	35
1970	84	154	22	26
1971	94	173	20	21
1972	102	190	25	25
1973	116	211	32	28
1974	124	227	39[c]	31
1975	130	259	47[c]	36
1976	137[d]	232[d]		
1977	144[d]	277[d]		
1978	150[d]	294[d]		
1979	166[e]	314[e]		

[a] Reference 67

[b] Reference 68

[c] Reference 58

[d] Reference 69

[e] Reference 4

TABLE 9-32. PRODUCTION AND SHIPMENTS OF ACETATE YARN[12 56 57 70 71 72]

	Production		Domestic shipments		Exports		Ending stock	
	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)	(gigagrams)	(million pounds)
1960	103.4	228.2	99.9	220.6	3.0	6.6	10.6	23.3
1961	112.8	249.0	109.1	240.8	4.6	10.1	9.7	21.4
1962	138.5	305.7	127.6	281.7	6.8	15.1	13.7	30.3
1963	140.2	309.5	138.1	304.9	5.3	11.8	10.4	23.0
1964	165.8	365.9	164.8	363.8	4.6	10.2	6.7	14.9
1965	177.2	391.2	165.9	366.3	4.2	9.3	13.8	30.5
1966	178.6	394.3	175.5	387.5	2.8	6.2	14.1	31.1
1967	192.8	425.6	190.7	420.9	3.6	8.0	12.6	27.8
1968	199.3	439.9	193.2	426.4	3.3	7.3	15.4	34.1
1969	206.2	455.2	201.4	444.7	3.1	6.9	17.0	37.6
1970	209.8	463.2	201.5	444.8	6.0	13.3	19.3	42.7
1971	203.5	449.3	195.8	432.3	7.2	16.0	19.8	43.7
1972	181.8	401.4	174.8	385.9	7.0	15.4	19.8	43.8
1973	198.1	437.2	177.7	392.3	24.3	53.6	15.9	35.1
1974	163.8	361.6	145.1	320.3	16.9	37.2	17.8	39.2
1975	136.5	301.3	133.0	293.7	12.8	28.2	8.4	18.6
1976	130.0	286.9	113.0	249.4	17.2	38.0	8.2	18.1
1977	127.7	282.0	117.5	259.4	10.9	24.0	7.6	16.7
1978	136.3	300.9	124.4	274.6	12.5	27.6	7.0	15.4
1979	143.6	316.6	130.6	288.4	14.4	31.8	5.4	11.8
1980	139.9	308.5	122.1	269.2	14.8	32.7	8.3	18.4

SRI forecast growth in production of acetate fiber for cigarette filtration tow at an average annual rate of 4.8 percent over the period 1975 to 1981. This growth rate was the result of projected growth in export markets of 5.7 percent and growth in domestic consumption of 4.3 percent over the period.[75] However, as mentioned, this projected growth in domestic consumption does not offset the projected decline in domestic consumption of acetate textile fiber, giving a net effect of 0.3 percent decline in consumption for all cellulose acetate fibers.

Textile Industries in its February 1979 issue projected that domestic mill consumption of rayon and acetate textile fibers together would decline 2.0 percent per year over the period 1977 to 1987.[49] This projection is not as straightforward as the SRI projections in that acetate textile fiber growth is not projected independently of the growth or decline in the market for rayon. In 1979, rayon comprised 65 percent of production of rayon and acetate textile fibers; therefore market conditions particular to rayon may be dominating those of the acetate textile fiber market in this aggregate projection.

Shortcomings exist in these projections from published sources. The projections from the Chemical Economics Handbook are for the period 1975-1981. The projections were derived from data no more recent than 1975. These projections are not applicable for forecasting growth through 1987, given general economic conditions from 1976-1980 and the specific effects that the higher prices of petroleum-derived products evidenced during 1976-1980 have on the costs of producing solvent-spun cellulose acetate fibers. The projections from Textile Industries are less than satisfactory due to the aggregation of the rayon and acetate markets.

Because of these shortcomings, the EPA estimated regression equations using historical production data for each of the two types of cellulose acetate fiber, textile fiber and cigarette filtration tow. The regression equations conducted in-house estimated projected growth in the production of these two fibers.

The regression equations estimated a relationship between production and time. This relationship was used to estimate production at future points in time. The equations estimated were of two forms. The first estimated the values of a and b in the following equation:

$$\text{production} = a(\text{year}) + b \quad .$$

The second regression equation estimated values of c and d in the following equation:

$$\text{natural log (production)} = c(\text{year}) + d.$$

Both equations are linear equations; the second is identified as "log"-linear, because the equation is estimated given values that are the natural logarithms of the production data.

For each type of fiber both log-linear and linear equations were estimated. As was the case with acrylic and modacrylic fibers, the two specifications were each estimated for three time intervals of annual production data: 1960-1979, 1970-1979, and 1975-1979.

For cellulose acetate textile fibers, the regressions estimated for data for 1975-1979 were judged to be the best for the purpose of forecasting future production. The log-linear growth equation projected growth in production to be 1.0 percent at an annually compounded rate. The growth rates estimated by linear regression were a range from 1.0 percent growth in 1981 declining to 0.9 percent growth in 1987. Log-linear regressions on production data for 1960-1979 and for 1970-1979 both estimated negative growth rates for acetate textile fiber consumption. Both evidenced a 0.6 percent average annual decline in production.

The growth rates estimated by regression of 1975-1979 production data were selected as the best indicators of future growth in production of cellulose acetate textile fibers. This time interval was chosen because of a stabilization in the demand for these textile fibers, which occurred in the late 1970s (see Table 9-32).[76]

For cigarette filtration tow, the best statistical fit was provided by the regression equations run on the 1970-1979 production data. The log-linear regression equation projected growth in production of cellulose acetate filtration tow at an average annual rate of 7.2 percent. The linear regression model projected average annual growth of 4.7 percent in 1981, declining to 3.6 percent in 1987.

As was the case with the regression equations estimated for acrylic and modacrylic fibers, the equations do not explicitly take into account the distinct effects of underlying market forces. Such influences as national economic trends, interfiber competition (substitutability, relative prices), and growth or decline in import and export markets are captured to some extent in the annual production data. However, there is some error in using this data as a basis for projection in that first, the effects are not estimated separately and second, the historical effects will not necessarily pertain in the future.

Specifically in the case of production of solvent-spun fibers from petroleum-derived polymer, the future effects of continually escalating polymer and solvent costs may not be as they were historically. It is not clear to what extent the growth rates derived by regression of historical production data are accurate in light of these shortcomings.

Of the published and derived growth rates for cellulose acetate fibers, those from published sources were not considered accurate for projection of capacity shortfalls in 1987. The Chemical Economics Handbook projections were based on data no more recent than 1975, and were only applicable for growth through 1981. The Textile Industries projection was for rayon and cellulose acetate textile fibers together; the applicability of the projection to consumption of cellulose acetate textile fiber alone is uncertain. Therefore, only the growth projections estimated by in-house regression were used to project capacity shortfalls.

As mentioned, for cellulose acetate yarn, regressions estimated using annual production data from 1975-1979 were chosen due to a stabilization in the demand for these textile fibers that occurred in the late 1970s.[76] These annual production data are:

Year	Production (gigagrams)
1975	136.5
1976	130.0
1977	127.7
1978	136.3
1979	143.6

The first regression, in direct linear form, estimated the equation to be:*

$$\underset{}{\text{prod}_t} = \underset{(3975.230)}{-2628.94000005} + \underset{(2.01)}{1.40000000}\ (t)$$

$$R^2 = 0.139$$

The estimated production levels and growth rates were:

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	1.0	143.1	150.6	2.6
1981	1.0	144.5	152.1	4.1
1982	1.0	145.9	153.6	5.6
1983	1.0	147.3	155.1	7.1
1984	0.9	148.7	156.5	8.5
1985	0.9	150.1	158.0	10.0
1986	0.9	151.5	159.5	11.5
1987	0.9	152.9	160.9	12.9

Estimated production is obtained by substituting the value of the year in the regression equation obtained. Estimated production capacity is the larger of 1) the capacity estimated to be in place in 1980, and 2) the capacity required, at a 95 percent capacity utilization rate, by estimated production. The capacity of cellulose acetate yarn estimated to be in place in 1980 is 148.0 gigagrams (see Table 9-23). Estimated capacity shortfall is the difference between the estimate of current capacity, and the capacity needed to meet the production estimates at a 95 percent capacity utilization rate, that is, the column "Estimated Production Capacity."

The second equation estimated was log-linear and resulted in the following equation:*

$$\ln(\text{prod}_t) = \underset{(28.744)}{-14.58050188} + \underset{(0.015)}{0.00987012}(t)$$

$$R^2 = 0.133$$

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*The standard error for each estimated value is provided in parentheses beneath each estimated value.

The equation was used to project production levels of:

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	1.0	142.9	150.4	2.4
1981	1.0	144.3	151.9	3.9
1982	1.0	145.8	153.5	5.5
1983	1.0	147.2	154.9	6.9
1984	1.0	148.7	156.5	8.5
1985	1.0	150.2	158.1	10.1
1986	1.0	151.6	159.6	11.6
1987	1.0	153.2	161.3	13.3

Estimated production, estimated production capacity, and estimated capacity shortfall were calculated as described above.

To project capacity shortfalls in the cigarette filtration tow market, regressions were estimated using annual production data from 1970-1979. These data are:

Year	Production (gigagrams)
1970	83.8
1971	93.8
1972	101.9
1973	116.0
1974	123.7
1975	130.0
1976	136.8
1977	143.6
1978	149.9
1979	165.3

The direct linear estimation was:*

$$\text{prod}_t = \underset{(749.821)}{-16251.09555556} + \underset{(0.380)}{8.29333333}(t)$$

$$R^2 = 0.986$$

---

*The standard error for each estimated value is provided in parentheses beneath each estimated value.

The equation was used to project production levels of:

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	4.9	169.7	178.6	4.6
1981	4.7	178.0	187.4	13.4
1982	4.5	186.3	196.1	22.1
1983	4.3	194.6	204.8	30.8
1984	4.1	202.9	213.6	39.6
1985	3.9	211.2	222.3	48.6
1986	3.8	219.5	231.1	57.1
1987	3.6	227.8	239.8	65.8

Estimated production is obtained by substituting the value of the year in the regression equation obtained. Estimated production capacity is the larger of 1) the capacity estimated to be in place in 1980 and 2) the capacity required, at a 95 percent capacity utilization rate, by estimated production. The capacity of cigarette filtration tow estimated to be in place in 1980 was 174.0 gigagrams, based upon 1979 production of 165.3 gigagrams (see Table 9-22) and a 95 percent utilization factor.* Estimated capacity shortfall is the difference between the estimate of current capacity, and the capacity needed to meet the production estimates at a 95 percent capacity utilization rate, that is, the column "Estimated Production Capacity."

The second equation, estimated by log-linear regression, was:**

$$\ln(\text{prod}_t) = \underset{(10.443)}{-136.92203615} + \underset{(0.005)}{0.07177904}(t)$$

$$R^2 = 0.963$$

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*Note that this capacity of 174.0 Gg, together with estimated capacity of 148.0 Gg for cellulose acetate yarn, is a total capacity for cellulose acetate and triacetate fiber of 322 Gg. This contradicts the data of Table 9-21 (total capacity = 296 Gg). The reported production data, the reported capacity data, and/or the capacity utilization assumption have associated errors.

**The standard error for each estimated value is provided in parentheses beneath each estimated value.

The equation was used to project production levels of:

Year	Growth Rate %	Estimated Production (gigagrams)	Estimated Production Capacity (gigagrams)	Estimated Capacity Shortfall (gigagrams)
1980	7.2	181.4	190.9	16.9
1981	7.2	194.9	205.2	31.2
1982	7.2	209.4	220.4	46.4
1983	7.2	224.9	236.7	62.7
1984	7.2	241.7	254.4	80.4
1985	7.2	259.7	273.4	99.4
1986	7.2	279.0	293.7	119.7
1987	7.2	299.7	315.5	141.5

Estimated production, estimated production capacity, and estimated capacity shortfall were calculated as described above for the linear estimation.

The projected capacity shortfalls, a range for each of the two cellulose acetate fiber types, are presented in Table 9-33. The 1982-1987 capacity shortfalls are based on the assumption that any capacity shortfall occurring before 1982 will be met by debottlenecking existing capacity or by constructing new capacity prior to 1982 (the first year that the NSPS will be in effect). Thus, only the capacity shortfalls arising in the years 1982-1987 will support new capacity in 1982-1987.

9.2 ECONOMIC IMPACT ANALYSIS

9.2.1 General Methodology

The purpose of this analysis is to estimate the economic impacts of the regulatory alternatives presented in Chapter 6. These alternatives will affect only new fiber producers who use volatile organic compounds as solvents. Most organic solvent-spun fibers are either acrylic/modacrylic or cellulose acetate/cellulose triacetate. The other specialty fibers produced with VOC solvent make up only 2.9 percent of solvent-spun fiber capacity.[77] Consequently, the economic impact analysis focuses on possible capacity expansion for acrylics and acetates and the impact of the regulatory alternatives on the cost, output and price of these fibers.

The impact analysis for each fiber type begins with a discounted cash flow analysis based upon the capital and operating costs developed by the EPA for each of the model plants. This analysis provides estimates of the

TABLE 9-33. CELLULOSE ACETATE YARN AND CIGARETTE FILTRATION TOW CAPACITY SHORTFALLS OVER 1982-1987

		1982		1987		
Fiber Type	Projection	Estimated Production (gigagrams)	Estimated Capacity (gigagrams)	Estimated Production (gigagrams)	Estimated Capacity (gigagrams)	1982-1987 Capacity Shortfall (gigagrams)
Cigarette Filtration Tow Model Plant 4	high (log-linear)	209.4	220.4	299.7	315.5	95.1
	low (linear)	186.3	196.1	227.8	239.8	43.7
Acetate Yarn Model Plant 5	high (log-linear)	145.8	153.5	153.2	161.3	7.8
	low (linear)	145.9	153.6	152.9	160.9	7.3

relative cost of each of the model plants and the cost impacts of the various emission control alternatives for each model plant. These values are therefore the basis for estimates of the cost impact and assessment of the financing burdens placed on the firms of the industry by the proposed emission controls.

The discounted cash flow analysis also provides an implicit price estimate for the output of each of the model plants under the alternate levels of emission control. These price estimates, in conjunction with the industry profiles, provide a basis for estimating the market impacts of the proposed regulations. The market impacts of interest include effects on price, sales, production and capacity.

9.2.2 New Acrylic and Modacrylic Facilities

For each of three types of model acrylic fiber plants, cost estimates were made for three alternate levels of VOC emissions control. Regulatory Alternative I, or the "baseline" level of control, utilizes a design based on current industry practice for new facilities. Regulatory Alternatives II and III represent VOC emissions control beyond the baseline level. Regulatory Alternative II represents application of additional controls to the primary remaining source of emissions from a new plant. Similarly, Regulatory Alternative III represents the application of additional controls to the second most significant remaining source of VOC emissions. As mentioned in the industry profile, expansion of acrylics capacity by American Cyanamid or Badische Corporation (together nearly one-fourth of 1980 industry capacity) will not be affected by these proposed regulatory controls so long as neither company utilizes volatile organic solvents.

9.2.2.1 Model Plant Cost Estimates. The fixed capital costs estimated by the EPA for the various degrees of VOC emissions control for the three model plants are summarized in Table 9-34. These figures show that under the control technologies considered by EPA, increases in VOC emissions control are associated with increases in the fixed investment made in the plants. These increases were nontrivial; Regulatory Alternative III's fixed capital costs were between 6 and 9 percent greater than the baseline. In addition to fixed capital costs, Table 9-34 shows working capital costs. Working capital, the

TABLE 9-34. CAPITAL AND OPERATING COSTS FOR THREE MODEL ACRYLIC FIBER PLANTS[a]

(million 1980 dollars)

Model plant	Plant description	Level of control	Fixed capital costs[b]	Working capital costs[c]	Total capital costs[d]	Annualized capital costs[e]	Annual solvent costs[f]	Annual polymer costs[g]	Other annual operating expenses[h]	Total annual operating expenses[i]	Total annual expenses[j]
Plant 1	Either suspension or solution polymerization with wet spinning and DMAc solvent; capacity of 45.36 Gg/year; produces acrylic fiber.	Baseline	72.2	8.9	81.1	5.1	4.6	50.0	51.6	106.2	111.3
		Regulatory Alternative II	76.0	8.8	84.8	5.4	3.7	50.0	52.2	105.9	111.3
		Regulatory Alternative III	78.7	8.8	87.5	5.5	2.8	50.0	52.6	105.4	110.9
Plant 2	Either suspension or solution polymerization with dry spinning and DMF solvent; capacity of 45.36 Gg/year; produces acrylic fiber.	Baseline	69.5	8.3	77.8	4.9	3.3	50.0	46.3	99.6	104.5
		Regulatory Alternative II	72.5	8.3	80.8	5.1	2.7	50.0	46.8	99.5	104.6
		Regulatory Alternative III	75.0	8.3	83.3	5.3	2.0	50.0	47.2	99.2	104.5
Plant 3	Suspension polymerization with dry spinning and acetone solvent; capacity of 20 Gg/year; produces modacrylic fiber.	Baseline	45.1	3.8	48.9	3.1	1.8	20.3	23.1	45.2	48.3
		Regulatory Alternative II	46.4	3.7	50.1	3.2	1.2	20.3	23.4	44.9	48.1
		Regulatory Alternative III	48.1	3.7	51.8	3.3	0.6	20.3	23.7	44.6	47.9

[a] Does not include polymerization or some raw materials, e.g., finish chemicals.

[b] Baseline costs (capital costs for process equipment and capital costs for solvent recovery equipment and, for regulatory alternatives, baseline costs plus component capital costs for each model plant under each option (Table 8-2).

[c] One-twelfth of total operating expenses.

[d] Sum of fixed capital costs and working capital costs.

[e] Annualized capital expenses for each year of a 30-year estimated life, plus 4.74 percent weighted cost of capital (see p. E-5) in real terms. Further information on annualized capital expenses is provided in Tables 9-35 and 9-38.

[f] Amount of makeup solvent required (model plant parameter) for plant capacity at 95 percent utilization, times mid-1980 cost of solvent.

[g] Amount of polymer required (model plant parameter) for plant capacity at 95 percent utilization, times mid-1980 cost of polymer.

[h] Annual operating costs (Table 8-2). Does not include annualized capital costs.

[i] Sum of solvent costs, polymer costs, and other operating expenses. Does not include annualized capital costs.

[j] Sum of annualized capital costs and total operating expenses.

average cash on hand required by the firm in order to finance purchases of labor, materials and product inventory, was estimated to be one-twelfth of the annual operating costs. The cost of maintaining this average cash balance was estimated to be the present value of the finance charges.

In order to assess the significance of these costs for the acrylic market in general, and new plant choice in particular, the fixed and working capital cost data were combined with associated operating costs. These additional expenses are summarized in Table 9-34. They are based upon 95-percent plant capacity utilization and physical input requirements derived in Chapter 6.

Solvent costs for DMAc and DMF were estimated using mid-1980 bulk prices from the Chemical Marketing Reporter: $1.51 per kilogram for DMAc, and $1.09 per kilogram for DMF.[78] Acetone was estimated to cost $0.62 per kilogram in mid-1980, based on conversations with producers of this chemical.[78,80] Because of increased solvent recovery associated with greater VOC emissions control, the make-up solvent required by each of the plants declines significantly between the baseline and Regulatory Alternative III. The associated solvent costs drop by $1.8 million for Plant 1, $1.3 million for Plant 2 and $1.2 million for Plant 3.

The regulatory alternatives promote improved solvent recovery at new, modified, and recontructed synthetic fibers plants, and this will reduce the makeup solvent requirements of these plants. These reductions are the basis for the computation of a solvent recovery credit: the amount of solvent saved times the market price of the solvent. These credits are employed in the economic analysis as an offset to the capital equipment and operating costs of improved solvent recovery.

Several producers have disputed the use of the market price as a means of valuing a unit of solvent saved. Specifically, firms which produced the solvent used in their synthetic fiber production activities claimed the market price was inflated relative to the internal accounting value used in firm investment and operating decisions. They therefore contended that the use of the market price overstated solvent recovery credits and understated the economic impact of the proposed standards.

The market price is nontheless considered to be the appropriate price for computing the solvent recovery credit. This is based upon the principle, generally accepted in economics, that in a competitive setting market prices represent the social opportunity cost of resources. Internal price of accounting cost valuation often reflect sunk cost or market structure phenomena which, while real enough to the firm, do not best reflect the value of a good to the economy as a whole. It is this later perspective which should be the basis for the economic analysis of a standard.

Furthermore, since the standard would be applied to new sources, it is not clear that internal accounting costs used in association with old plants would even be viewed by the firms as the appropriate measure of the worth of solvent. This is especially true for a vertically integrated firm, which would require new solvent capacity if it is to continue to supply its synthetic fiber facilities with solvent. The opportunity cost of solvent to such a firm is the market price of the solvent from another source.

Polymer costs were difficult to estimate because no well-developed market for polyacrylonitrile exists. Acrylic manufacturers actually purchase the monomer acrylonitrile and polymerize it in-house to produce polyacrylonitrile. The decision to examine the spinning and finishing phases of production in isolation from polymerization in this analysis has the effect of requiring the estimation of internal or accounting price for a major process input. The price of polyacrylonitrile was estimated by taking the mid-1980 price of acrylonitrile from the Chemical Marketing Reporter and adding a processing value of \$0.33 per kilogram.* This procedure yielded a polyacrylonitrile price estimate of \$1.16 per kilogram. For Plant 3, the modacrylic plant, the polymer price was adjusted to reflect the 40-percent vinylidene chloride/60-percent acrylonitrile mix that is standard for modacrylic polymer. The mid-1980 price of vinylidene chloride was estimated at \$0.62 per kilogram. Again, a processing value of \$0.33* per kilogram was added to incorporate value added in polymerization. Modacrylic polymer price for Plant 3 was therefore estimated to be $1.07 per kilogram. The quantity of polymer required as input does not vary by level of emissions control; therefore the polymer costs for each model plant do not vary by regulatory alternative.

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*Derived from data in the Chemical Economics Handbook Marketing Research Report on Acrylic and Modacrylic Fibers.

The category "Other Operating Expenses" shown in Table 9-34 includes labor, administration, utilities, and insurance costs. These expenses rose slightly as a result of increased VOC emissions control.

Operating expenses plus working capital make up around 95 percent of the annual expenses incurred by the firms operating these model plants. The cost of additional emission control equipment, while a significant fraction of fixed costs, is not a major portion of the overall expenditures anticipated by a firm considering building and operating a new acrylic facility.

9.2.2.2 Present Discounted Cash Flow Analysis. The capital and operating costs for each model plant and each option were employed as inputs in a cash-flow model to estimate the net present cost and implicit producer price for each plant for each alternative. The objective of this analysis is to determine (1) which of the model plants would be least costly, and (2) what impacts on costs (and prices) the various levels of VOC emission control would have. The results of this analysis are summarized in Table 9-35.

The present discounted costs are shown for each plant both before and after normalization by plant capacity. The discount rate employed to make these discounted cash flow calculations was the estimated weighted average cost of capital (WACC) for firms producing acrylic, modacrylic, and cellulose acetate fibers. The WACC was adjusted by an estimate of long-run inflationary expectation so as to yield a real discount rate of 4.74 percent for use in the analysis. The details of these calculations and adjustments are contained in Appendix E.

The 4.74 percent estimate of the industry's real weighted average cost of capital was the highest of the range of WACCs estimated. The EPA chose this estimate for the discounted cost and implicit price calculations because an industry's required rate of return (for which the WACC is a proxy) is a component of costs, and hence the higher the

TABLE 9-35. DISCOUNTED PLANT COSTS AND IMPLICIT PRICE FOR MODEL ACRYLIC AND MODACRYLIC FIBER PLANTS[a]

Model plant	Level of control	Discounted cost of plant (million 1980 dollars)	Normalized discounted cost of plant (million dollars per gigagram capacity)	Implicit price of fiber (dollars per kilogram)
Plant 1 (capacity of 45.36 Gg/yr)	Baseline	1,778.6	39.2	2.61
	Regulatory Alternative II	1,777.6	39.2	2.60
	Regulatory Alternative III	1,772.3	39.1	2.60
Plant 2 (capacity of 45.36 Gg/yr)	Baseline	1,670.3	36.8	2.45
	Regulatory Alternative II	1,671.7	36.9	2.45
	Regulatory Alternative III	1,669.4	36.8	2.45
Plant 3 (capacity of 20 Gg/yr)	Baseline	771.9	38.6	2.57
	Regulatory Alternative II	768.4	38.4	2.56
	Regulatory Alternative III	765.2	38.3	2.55

[a] Present discounted values were computed using the following economic parameters: thirty year plant life, 4.74 percent real rate of discount, fourty-nine percent effective tax rate, ninety-five percent plant utilization, and ten percent investment tax credit.

WACC, the higher the product price must be to recover all costs. The EPA has chosen that estimate of the range of WACC estimates that portrays the "worst case" scenario, in the sense that the higher the WACC, the greater would be the economic burden associated with investing in additional capacity.

Model Plant 2 is the most attractive alternative among the two acrylic fiber plant types: its present discounted costs are approximately 6 percent lower than those for Model Plant 1. The modacrylic plant, Model Plant 3, costs less than the other two model plants because of its smaller capacity. When normalized to an equal capacity, the cost of the modacrylic facility is slightly less than the cost of Model Plant 1, but greater than that of Model Plant 2.

The striking thing about the discounted plant costs is that costs for two of the three model plants decline as emissions control increases. For the third model plant (Model Plant 2), Regulatory Alternative III is no more costly than baseline control, and Regulatory Alternative II is only slightly more costly. Even in present-value terms, in which a dollar of initial investment is weighted more heavily than a dollar of future operating costs, the model plants, for the most part, become more attractive investments as the level of emissions control increases. The driving force behind this result is the annual saving in the cost of solvents. With greater emissions control, the value of the additional solvent that is captured and recycled more than offsets the increased cost of the additional control equipment and maintenance.

9.2.2.3 Profit and Price Impact of Emissions Control. Given the results of the discounted cash-flow analysis, the profit and price impacts of emissions control are easy to bracket. At the extremes, the change in costs associated with increased emission control may be absorbed entirely by consumers, in the form of price changes, or by producers, in the form of changes in the cost of doing business. In the case of acrylic and modacrylic fibers, increased emissions control confers benefits to the party or parties impacted by the change, with only one exception, moving from baseline control to regulatory Alternative II control for Model Plant 2. The outcome for the full-price increase and full-cost absorption cases are shown below.

Full-cost pass through
(percent)

Level of control	Price change Plant 1	Plant 2	Plant 3
Baseline to Regulatory Alternative II	-0.4	0.0	-0.4
Baseline to Regulatory Alternative III	-0.4	0.0	-0.8

Full-cost absorption
(million 1980 dollars)

Level of control	Present value of cost change Plant 1	Plant 2	Plant 3
Baseline to Regulatory Alternative II	-1.0	+1.4	-3.5
Baseline to Regulatory Alternative III	-6.3	-0.9	-6.7

Increased emissions control increases the cost of new facilities in only one case, and in no case increases the price of output.

These results do, however, deserve some qualification. The declines in the present discounted cost of the plants as emission control increases are very small, all less than 1 percent of total discounted costs. Declines of this magnitude may well be the result of minor errors in cost estimation. The apparent consistency in the cost trends across plants may actually reflect nothing more than a consistent error in the raw data or cost estimation procedure.

Furthermore, since these control technologies involve the installation of relatively straightforward enclosure systems, these cost trends suggest that acrylic producers might well retrofit their current spinning lines. Although the Du Pont plant was built with such enclosures, the other acrylic producers have not retrofitted their facilities. While recognizing these considerations, the EPA believes that for the range of control and technology choices examined here, the economic impact on the cost or price of acrylics from new production capacity is relatively small and is quite likely to be negative.

9.2.2.4 Capacity Projections Reconsidered. Ordinarily, one would expect that the supply of synthetic fiber would be a fairly smooth function of the price of output and the price of inputs. The synthetic fiber industry has recently emerged from a period of soft demand relative to capacity. Theoretically, in such circumstances firms will remain in production so long as they are able to cover their variable costs. Firms operating plants whose revenues from production do not cover the variable costs of that production will close those plants. As noted in the industry profile, Union Carbide left the acrylic and modacrylic industry in 1975, by closing its modacrylics plant. Industry earnings are only now beginning to recover from the soft demand experienced during the 1974-1975 recession.[81]

In such circumstances, it is quite likely that additions to capacity must be preceded by a significant increase in the price of fiber relative to operating costs. Established plants may continue to produce at the lower prices because the capital costs are sunk. However, new capacity can only be justified when the price is high enough to make the expectation of future earnings and profits competitive with other investments. This set of circumstances may result in a discontinuous supply function for acrylic and modacrylic fibers, as pictured in Figure 9-1. In that figure the current capacity of the industry is Q_1^*. The supply function S_0 S_0 is discontinuous at Q_1^*: increases in industry supply beyond Q_1^* will require a price P_2 P_0. With the supply function, S_0 S_0, the dynamics of industry capacity expansion may be characterized as follows. For a demand function D_0 D_0, the industry is operating well below capacity, price is P_0, and output and consumption of fiber are equal at Q_0. Over time, however, the demand for the fiber increases (shifts to the right) to D_1 D_1, but capacity and production remain at Q_1^* once that capacity is reached. The price of fiber, however, rises to P_1. Further increases in demand result only in price changes until price P_2 is attained. At that price new capacity is financially justified and shifts in demand to D_2 D_2 result in output increases (to Q_2) with little or no further effect

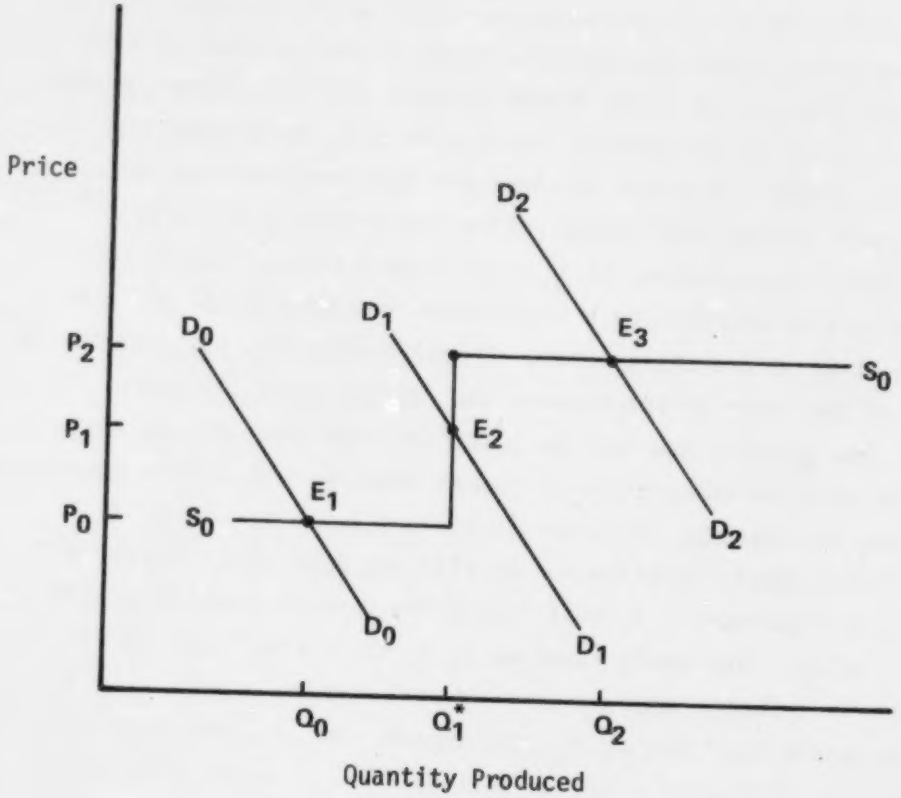

Figure 9-1. Market With a Supply Discontinuity

on the price P_2. While this is a highly stylized portrayal of a dynamic market situation, it underscores the possibility that new acrylic and modacrylic capacity will not automatically be constructed as current capacity is approached. A price barrier may first have to be overcome. This characterization of supply and demand is intended to reflect the conditions of the current acrylic and modacrylic market. In the following paragraphs, the current market situation and the position of the current market equilibrium (E_n) are considered.

As noted above, the evidence of an earnings slump and firm withdrawal support the notion of a discontinuity in supply. Another indication of the existence of a supply discontinuity, as well as of the particular position of the market equilibrium, might be obtained through a comparison of the current market price and implicit price for the fiber, which emerged from the discounted cash flow analysis. Ranges for these values are presented below.

	Prices (dollar per kilogram)	
	Market	Implicit
Acrylic		
Model Plant 1	1.94-2.49[82,83,84]	2.60-2.61
Model Plant 2	1.94-2.49[82,83,84]	2.45
Modacrylic		
Model Plant 3	2.38-2.58[85*]	2.55-2.57

Because Model Plants 1 and 2 are also capable of producing modacrylic, it is anticipated that a firm constructing new acrylic or modacrylic facilities would build a plant like Model Plant 2, which is the least cost plant. The implicit price estimated for Model Plant 2 falls just within the high end of the range for acrylic prices reported for mid-1980.

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*These prices are for January 1981, not mid-1980. Mid-1980 prices were not available from the source.

The market prices presented here are a very broad range, reflecting differences in the prices of various types of acrylics, for example, thick fibers for use in manufacturing carpets and thin fibers for use in apparel.

Additionally, market prices for acrylic and modacrylic fibers have recently been quite volatile. By March 1981, acrylic fiber prices were reported ranging from $2.31 to $2.69,[83,84] and modacrylic prices were reported ranging from $2.60 to $2.80.[85] Given the recent increases in prices for inputs to acrylic and modacrylic production (see Table 9-36), it is quite likely that modacrylic and acrylic price increases were lagging behind input price increases. If indeed a supply discontinuity existed in the market for acrylic and modacrylic fibers between the market prices for these fibers in mid-1980 and the implicit prices necessary to justify new capacity construction, this price differential appears to have been traversed. It seems quite reasonable that producers of acrylic and modacrylic prices would no longer be deterred from capacity addition, in that current market prices of acrylic and modacrylic fibers justify the construction of new plants. Therefore, the cost associated with constructing plants to meet either baseline levels of control or NSPS levels of control do not seem to be prohibitive to construction of new plants to meet the capacity shortfall projected for the acrylics and modacrylics fiber industry (see Section 9.1.2.4 above).

9.2.3 New Acetate and Triacetate Facilities

The fixed capital costs estimated for two types of new acetate fiber capacity were presented in Chapter 8. The model plants considered both employ acetone solvent and dry spinning but produce different finished products due to processing differences. Plant 4 produces cigarette filtration tow and Plant 5 produces textile fibers. As in the case of acrylics and modacrylics three degrees of VOC emission control are analyzed: Regulatory Alternative I, the baseline or current industry practice for new plants; Regulatory Alternative II, application of additional controls to the major remaining source of VOC emissions; and Regulatory Alternative III, additional control of both the first and second most significant remaining sources.

TABLE 9-36. TIME TREND FOR INPUTS
(current $/Kg)

	July 20, 1981	Jan 12, 1981	July 28, 1980	Dec 31, 1979	July 16, 1979	Feb 5, 1979
Acrylonitrile	.44	.375	.375	.305	.25	.25
DMAc	.685	.685	.685	.685	.515	.515
DMF	.59	.59	.495	.43	.43	.43
Acetone	.31-.33	.29-.31	.29-.31	.24-.26	.22-.24	.18-.20

9.2.3.1 Model Plant Cost Estimates. The fixed capital costs as estimated by the EPA for various degrees of control are summarized in Table 9-37. These data show that fixed equipment costs increase with the level of VOC emissions control. The size of this increase varies substantially between the plants. Between the baseline level of control and Regulatory Alternative III, fixed capital costs rise 6.3 percent for Plant 4 and 12.4 percent for Plant 5. As in the case of acrylic and modacrylic model plants, the working capital costs were estimated to be the present value of maintaining an average cash balance equal to one-twelfth of annual operating costs.

Estimated annual operating expenses for the cellulose acetate model plants are also summarized in Table 9-37. These operating costs were developed in a fashion similar to that described above for acrylics.

The costs were estimated for the physical input requirements presented in Chapter 6, assuming 95-percent capacity utilization. Cost of solvent was assumed to be $0.62 per kilogram and was based on EPA communications with producers of this solvent.[79,80] Because of the increased recovery of solvents for additional levels of VOC control, the cost of solvent for Plant 4 dropped $0.7 million per year of operation between the baseline and Regulatory Alternative II, and $1.0 million per year of operation between the baseline and Regulatory Alternative III. Similarly, the cost of solvent for Plant 5 dropped $0.9 million and $1.3 million per year between the baseline and Regulatory Alternatives II and III, respectively.

The cost of cellulose acetate polymer was estimated to be $1.95 per kilogram, as reported in the July 28, 1980, issue of the Chemical Marketing Reporter. The cost of polymer per year of operation does not vary by level of emissions control because the quantity of polymer required as a process input is constant.

Other operating expenses rose slightly as the level of VOC emissions control increased. These increases were 3.5 percent for Model Plant 4 and 6.3 percent for Model Plant 5 as emissions control increased from the baseline to Regulatory Alternative III.

9.2.3.2 Present Discounted Cash Flow Analysis. The effect of these opposing expenditure movements on the discounted cost of the

TABLE 9-37. CAPITAL AND OPERATING COSTS FOR TWO MODEL CELLULOSE ACETATE FIBER PLANTS[a] (million 1980 dollars)

Model plant	Plant description	Level of control	Fixed capital costs[b]	Working capital costs[c]	Total capital costs[d]	Annualized capital costs[e]	Annual solvent costs[f]	Annual polymer costs[g]	Other annual operating expenses[h]	Total annual operating expenses[i]	Total annual expenses[j]
Plant 4	Solution polymerization with dry spinning and acetone solvent; capacity of 22.7 Gg/year; produces cigarette filtration tow	Baseline	67.1	5.8	72.9	4.6	1.7	42.1	25.7	69.5	74.1
		Regulatory Alternative II	70.1	5.8	75.9	4.8	1.0	42.1	26.4	69.5	74.3
		Regulatory Alternative III	71.3	5.8	77.1	4.9	0.7	42.1	26.6	69.4	74.3
Plant 5	Solution polymerization with dry spinning and acetone solvent; capacity of 22.7 Gg/year produces textile fibers	Baseline	83.6	6.0	89.6	5.7	2.3	42.1	27.1	71.5	77.2
		Regulatory Alternative II	91.8	6.0	97.8	6.2	1.4	42.1	28.5	72.0	78.2
		Regulatory Alternative III	94.0	6.0	100.0	6.3	1.0	42.1	28.8	71.9	78.2

[a] Does not include polymerization for some raw materials, e.g., finish chemicals.

[b] Baseline costs (capital costs for process equipment and capital costs for solvent recovery equipment and, for regulatory alternatives, baseline costs plus component capital costs for each model plant under each option (Table 8-2).

[c] One-twelfth of total operating expenses.

[d] Sum of fixed capital costs and working capital costs.

[e] Annualized capital expenses for each year of a 30-year estimated life, plus 4.74 percent weighted cost of capital (see p. E-5) in real terms. Further information on annualized capital expenses is provided in Tables 9-35 and 9-38.

[f] Amount of makeup solvent required (model plant parameter) for plant capacity at 95 percent utilization, times mid-1980 cost of solvent.

[g] Amount of polymer required (model plant parameter) for plant capacity at 95 percent utilization, times mid-1980 cost of polymer.

[h] Annual operating costs (Table 8-2). Does not include annualized capital cost.

[i] Sum of solvent costs, polymer costs, and other operating expenses. Does not include annualized capital costs.

[j] Sum of annualized capital costs and total operating expenses.

plants is shown in Table 9-38. The results for Model Plants 4 and 5 are different from those for the acrylic and modacrylic plants, where discounted costs were found to decline as emission control increased. In the case of the cellulose acetate plants, discounted costs and associated implicit prices either are stable or increase as the level of emission control increases. Solvent recovery credits are not sufficiently large in some cases to completely offset increases in capital and operating costs due to increasing levels of emission control.

9.2.3.3 Profit and Price Impact of Emissions Control. As is the case for acrylics and modacrylics, the estimated price and cost impacts of the proposed levels of VOC emissions control for cellulose acetate fibers were based upon the results of the discounted cash flow analysis. This was done for each of the extreme cases: full-price pass through to consumers and full-cost absorption of the price impact by producers. These calculations are presented below.

Full-cost pass through
(percent)

	Price change	
Level of control	Plant 4	Plant 5
Baseline to Regulatory Alternative II	+0.3	+1.7
Baseline to Regulatory Alternative III	+0.3	+1.7

Full-cost absorption
(million 1980 dollars)

	Present value of cost change	
Level of control	Plant 4	Plant 5
Baseline to Regulatory Alternative II	+3.0	+16.2
Baseline to Regulatory Alternative III	+2.6	+16.8

TABLE 9-38. DISCOUNTED PLANT COSTS AND IMPLICIT PRICE FOR MODEL CELLULOSE ACETATE FIBER PLANTS[a]

Model plant	Level of control	Discounted cost of plant (million 1980 dollars)	Normalized discounted cost of plant (million dollars per gigagram capacity)	Implicit price of fiber (dollars per kilogram)
Plant 4 (capacity of 22.7 Gg/yr)	Baseline	1184.4	52.2	3.47
	Regulatory Alternative II	1187.4	52.3	3.48
	Regulatory Alternative III	1187.0	52.3	3.48
Plant 5 (capacity of 22.7 Gg/yr)	Baseline	1233.0	54.3	3.62
	Regulatory Alternative II	1249.2	55.0	3.67
	Regulatory Alternative III	1249.8	55.1	3.68

[a] Present discounted values were computed using the following economic parameters: thirty year plant life, 4.74 percent real rate of discount, fourty-nine percent effective tax rate, ninety-five percent plant utilization, and ten percent investment tax credit.

The increases in emissions control increase the price of fiber produced by new facilities when moving from the baseline level of control to Regulatory Alternative II for both Model Plants 4 and 5. However, no further price increases result from the move from Regulatory Alternative II level of control to Regulatory Alternative III level of control. The output of Model Plant 4 is estimated to increase 0.3 percent due to either of the regulatory alternatives; the output of Model Plant 5 is estimated to increase 1.7 percent due to either of the regulatory alternatives. Full cost impact absorption by producers results in increases in the present value of costs of operation in all cases except that of moving from Regulatory Alternative II to Regulatory Alternative III with Model Plant 4. The present value cost increases range from $2.6 million to $16.8 million.

The same qualifications mentioned with respect to the accuracy of the acrylic and modacrylic implicit price and cost results also apply to the results for cellulose acetate fibers. In addition, it should be noted that the relative price of solvents has recently been rising very rapidly. If the trend continues, the credits for additional solvent recovery will grow faster than the costs of installing additional recovery equipment, and cost savings or price reductions might result.

9.2.3.4 Capacity Projections Reconsidered. As discussed in Section 9.2.2.4, there is some evidence that a discontinuous supply function may characterize the synthetic fiber industry. To assist in determining whether such considerations might adversely affect the projections of new cellulose acetate capacity presented in Section 9.1.3.4, the implicit prices calculated from the discounted cash flow analysis for cellulose acetate were compared with the mid-1980 market prices of these fibers. This comparison is presented below.

	Prices (dollars per kilogram)	
	Market	Implicit
Model Plant 4 (cigarette filtration tow)	2.40[86]	3.47-3.48
Model Plant 5 (textile fibers)	2.67-2.98[82]	3.62-3.68

For cigarette filtration tow, the implicit prices are nearly 50 percent greater than the observed market price in mid-1980. Additionally, the market price reported in March of 1982 for cigarette filtration tow was $2.71-$2.76,[87] still substantially below the implicit price suggested by the model plant analysis. This divergence of approximately one dollar per kilogram between mid-1980 market tow prices and the implicit price required to make new plant construction profitable at first glance suggests that new plants would not actually be constructed at the rate projected above in Section 9.1.3.4.

In the past, manufacturers of cellulose acetate fibers have converted cellulose acetate yarn and staple capacity to cigarette filtration tow capacity, apparently due to increases in tow prices that provided greater earnings opportunities than were available from yarn or staple production. If firms were able to continue to convert cellulose acetate yarn and staple capacity to filtration tow capacity, the capacity shortfall for cigarette filtration tow could be met by converted plants that would not fall under the NSPS, so long as emissions did not increase and conversion costs were less than 50 percent of the capital costs estimated for a new facility. A representative of Tennessee Eastman reported that conversion of yarn facilities to tow facilities had been accomplished previously in approximately one year, and for less than 50 percent of estimated capital costs for a new facility.[88] Economic theory suggests that producers will continue to convert yarn and staple capacity to tow capacity if the price of tow increases relative to the price of yarn. However, industry analysts state that the cellulose acetate yarn market is currently stable and that yarn capacity has already been converted to the extent that producers are willing to do so.[88,89]

Assuming that there will be no further conversion of capacity, as industry suggests, the market price of cigarette filtration tow must rise to approximately $3.47 per kilogram, before producers will build new capacity, even at the baseline level of control.

Figure 9-2 depicts the hypothesized domestic market for cellulose acetate filtration tow. Domestic demand for cellulose acetate filtration tow is currently D_oD_o. The demand curve D_oD_o intersects the supply

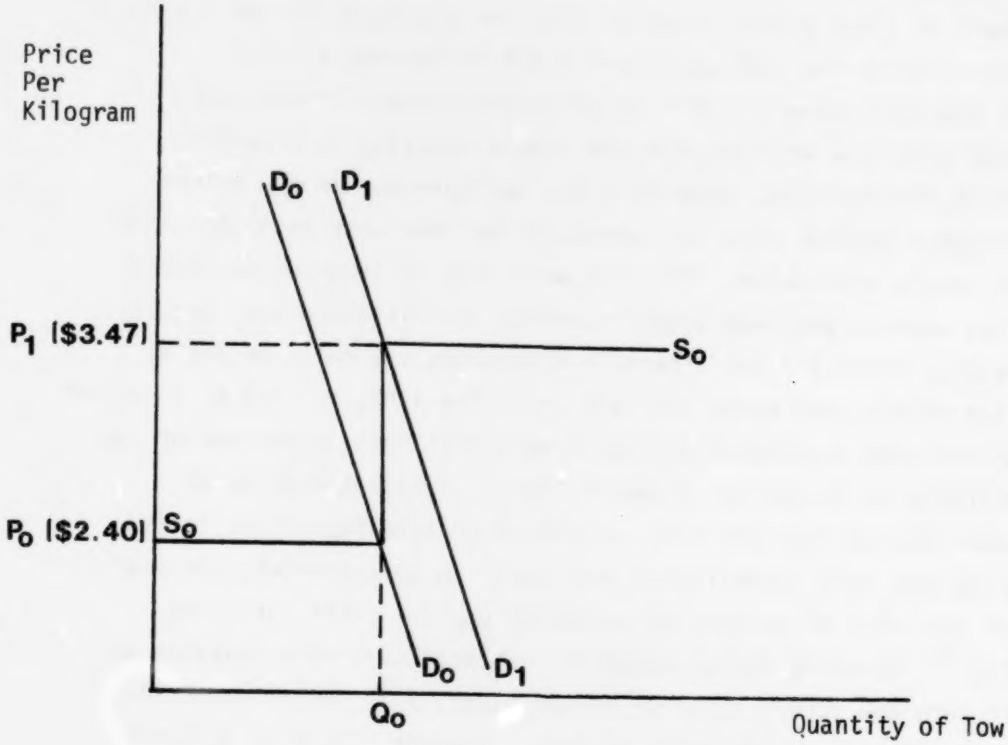

Figure 9-2. Domestic Market for Cellulose Acetate Filtration Tow

curve S_0S_0 at quantity Q_0, which reflects that the industry is currently operating at maximum capacity utilizaton, and at price P_0, equal to \$2.40 per kilogram. Demand for cigarette filtration tow is highly price inelastic, as reflected in the nearly vertical demand curve, D_0D_0. The market price for tow will move to P_1, equal to \$3.47 per kilogram, only if demand shifts from D_0D_0 to D_1D_1.

The supply curve S_0S_0 is depicted as a vertical line between price P_0 and price P_1, reflecting perfectly inelastic supply of tow to the domestc market between these two prices. Three assumptions are required to characterize this segment of the supply curve in this manner. First, as price moves from P_0 to P_1, domestic producers will continue to export that amount of tow that they were exporting at price P_0. Second, as price moves from P_0 to P_1, domestic cigarette producers will continue to import the same amount of tow as they imported at P_0. Third, domestic cigarette producers will not substitute other materials for tow in cigarette production (i.e., paper or charcoal).

Given that demand is highly inelastic and that supply is perfectly inelastic, little shift in demand is required to raise market price from P_0 (\$2.40) to P_1 (\$3.47).

The elasticity of demand for cigarette filtration tow was estimated by the EPA and indeed found to be highly inelastic. Elasticity of demand refers to the percent change in the quantity demanded of a product due to a 1 percent change in the price of that product. The price elasticity for tow was derived from the price elasticity for cigarettes (estimated to be -0.5)90 and the cost share of filter tow in cigarettes (estimated by the EPA to be 0.015). Cigarette filtration tow was estimated to have an elasticity of demand of -0.0075, that is, a 1 percent change in its price would result in only a .0075 percent change in the quantity of tow demanded.

Characterizing supply as perfectly inelastic between P_0 and P_1 requires three assumptions, as mentioned above. The first assumption, that cigarette producers will not substitute paper or charcoal filters for cellulose acetate filtration tow, is supported by evidence (in the Chemical Economic Handbook's Marketing Research Report on Cellulose Acetate and Triacetate Fibers) that cigarette smokers prefer the taste of cellulose acetate filters to that of paper filters, and that charcoal filters have decreased in popularity in recent years.

The other two assumptions, regarding foreign trade effects, are that neither the quantity of tow exported (approximately a third of domestic production) nor the quantity of tow imported (currently none) will be affected by the rising price of domestic tow. It is likely that increases in the price of domestic tow will have some effect upon these two components of foreign trade. However, these effects were not incorporated due to the lack of necessary data and the scope of this analysis.

Using these supply assumptions, the demand elasticity estimates, and the projected rate of growth for cigarette filtration tow, the EPA estimated the time it would take for demand to shift from D_oD_o to D_1D_1, and found this time interval to be less than one month. The uncertainty regarding the supply assumptions and demand elasticity and rate of growth estimates brings into question the accuracy of this estimate of the time required for the demand shift. However, even given this uncertainty, it is reasonable to conclude that the time interval will not be of such great duration as to significantly delay construction of new plants.

Turning to the market for cellulose acetate textile fibers, the implicit price is substantially greater than the market price for these fibers. Given the estimated 1982-1987 capacity shortfall of 7.3 to 7.8 gigagrams, and the contention that industry would be inclined to build in plant unit capacities of 22.7 gigagrams, the EPA has concluded that there will be no additions to cellulose acetate yarn capacity in the period 1982-1987. This conclusion is qualitatively supported by an analyst within the cellulose acetate yarn industry who characterizes the growth in demand for these fibers as stable.[88]

9.3 POTENTIAL SOCIOECONOMIC AND INFLATIONARY IMPACTS

Executive Order 12291 requires that the inflationary impacts of major legislative proposals, regulations, and rules be evaluated. The proposed NSPS would be considered a major action (thus requiring the preparation of a Regulatory Impact Analysis) if any of the following criteria apply:

1. An annual effect on the economy of $100 million or more;
2. A major increase in costs or prices for consumers, individual industries, Federal, State or local government agencies, or geographic regions; or
3. Significant adverse effects on competition, employment, investment, productivity, innovation, or on the ability of United States based enterprises to compete with foreign-based enterprises in domestic or export markets.

Even in a "worst case" scenario, the standards do not approach an annual effect on the economy of $100 million or more.* Assuming that in the case of acrylics/modacrylics and cigarette filtration tow the high growth projections are the most accurate, two acrylic/modacrylic plants (Model Plant 2), each operating at 81 percent utilization, and four cellulose acetate filtration tow plants (Model Plant 4), each operating at 95 percent utilization, will be built in the years 1982 to 1987. In the case of Regulatory Alternative II level of control, each acrylic/modacrylic plant will have annualized costs of $0.2 million over the baseline. Each cellulose acetate filtration tow plant will also have annualized costs of $0.2 million over the baseline. Total annual effect on the economy would therefore be $1.2 million. In the case of Regulatory Alternative III, acrylic/modacrylic plant annualized costs are once again $0.2 million over the baseline. Cellulose acetate filtration tow plants again have annualized costs of $0.2 million greater than the annualized costs of plants under baseline level of control. The annual effect on the economy would therefore be $1.2 million, equivalent to the annual costs of Regulatory Alternative II.

With regard to the second criterion, a major increase in cost or prices, the maximum price impact due to either regulatory alternative is 1.7 percent. This impact is for Model Plant 5, cellulose acetate yarn, for which no capacity is projected to be built. Acrylic/modacrylic prices either remain constant or decrease due to the regulatory alternatives, and the price of cigarette filtration tow increases only 0.3 percent (under either alternative). These are not major cost increases.

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*Certain qualifications concerning the accuracy of the estimates of discounted plant costs and implicit fiber prices are presented in Section 9.2 and should be borne in mind.

Finally, it is not evident that either of the regulatory alternatives would have significant adverse effects on competition, employment, productivity, innovation, or domestic competitive advantage.

With regard to effects upon small business in the industry, none of the firms identified are small businesses as categorized by the Small Business Administration for firms in this industry. So long as these firms are those that build new capacity in this industry, there will be no adverse effects on small businesses.

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APPENDIX A

EVOLUTION OF THE PROPOSED STANDARD

APPENDIX A. EVOLUTION OF THE PROPOSED STANDARDS

A.1 INTRODUCTION

The Clean Air Act Amendments of 1970 strengthened the Air Quality Act of 1967 by including authority to promulgate standards of performance for major new sources (Section 111) and to promulgate national emission standards for existing sources of hazardous pollutants (Section 112). During the 1977 hearings on the Clean Air Act, Congress received testimony on the need for more rapid standard development. There was concern that not all sources which had the potential to endanger public health or welfare were controlled. These concerns were reflected in the Clean Air Act Amendments of 1977. The Amendments require promulgation of the new source standards on a greatly accelerated schedule.

The Priority List (40 CFR 60.16, August 21, 1979) identifies various sources of emissions on a nationwide basis in terms of quantities of emissions from source categories, the mobility and competitive nature of each source category, and the extent to which each pollutant endangers health and welfare. The Priority List reflects the Administrator's determination that emissions from the listed source categories contribute significantly to air pollution and is intended to identify major source categories for which standards of performance are to be promulgated. The sources on the list are ranked in decreasing order of priority; the synthetic fibers industry ranks 25th on the list of 59 source categories recommended for control.

The standard setting mechanism, as provided for under Section 111 of the Clean Air Act, as amended, was applied to sources emitting volatile organic compounds (VOCs) from synthetic fiber manufacturing plants with the intention of developing an NSPS for new and modified facilities.

A.2 CHRONOLOGY

The following chronology lists important events that occurred during the development of the background information document for the synthetic fibers NSPS.

CHRONOLOGY

DATE	ACTIVITY
11/7/79	Initial meeting held between representatives of the Man-Made Fiber Producers Association and EPA to establish contact between the organizations.
11/27/79	Plant visit made to the Allied Chemical Company - Chesterfield County, Virginia, to gather background information.
11/28/79	Plant visit made to the Badische Corporation - Williamsburg, Virginia, to gather background information.
12/13/79	Plant visit made to the Tennessee Eastman Company - Kingsport, Virginia, to gather background information.
1/15/80	Plant visit made to the Avtex Company in Nitro, West Virginia - to gather background information.
1/22/80	Plant visit made to the American Enka Plant - Lowland, Tennessee, to gather background information.
3/19/80	Mailed Survey Questionnaire to plants scheduled for visits.
4/1/80	Plant visit to the Monsanto Textiles Company-Decatur, Alabama.
4/3/80	Sent EPA 114 letters to the Tennessee Eastman Company, the Avtex Fibers Company, and the Celanese Fibers Corporation.
4/8/80	Sent EPA 114 letter to the Badische Corporation-acrylic fiber plant in Williamsburg, Virginia.
4/11/80	Plant visit to the American Cyanamid Company-Pensacola, Florida.
4/29/80	Plant visit to DuPont's acrylic fiber plant, in Camden, South Carolina.

CHRONOLOGY (continued)

DATE	ACTIVITY
4/30/80	Visited Virginia State Air Pollution Agency to review State files on Celanese Narrows Plant and DuPont Waynesboro Plant.
5/1/80	Plant visit to DuPont's acrylic fiber plant in Waynesboro, Virginia.
5/28/80	Plant visit to the Celanese Corporation's cellulose acetate plant in Rock Hill, South Carolina.
5/29/80	Meeting with Man-Made Fiber Producers Association.
6/2/80	Reviewed standard development with North Textile Association, Boston, Massachusetts; solicited comments on Phase I study (portions).
6/27/80	Section 114 letter request sent to Monsanto for additional information on the Decatur, Alabama, fiber plant.
8/6-8/8/80	Pre-test survey conducted at the Monsanto plant in Decatur, Alabama.
8/11/80	Semi-quantitative pre-test survey conducted at the Celanese plant in Narrows, Virginia.
9/22/80	Emission evaluation tests conducted at the DuPont plant in Camden, South Carolina.
10/27/80	Emission evaluation tests conducted by at the Monsanto plant in Decatur, Alabama.
11/05/80	Draft BID Chapter 3 - 7, and 9.1 mailed to industry for comment and input.
3/6/81	Final Section 114 letter sent to Monsanto requesting more process information for the Decatur, Alabama, plant.
7/29/81	Meeting at EPA/OAQPS with Celanese Fibers Company to discuss apparent discrepancies in the data provided by Celanese Fibers Company for two of their plants.
9/15/81	Meeting at EPA/OAQPS with representatives of Tennessee Eastman Company to review their concerns with the NAPCTAC draft BID.

CHRONOLOGY (continued)

DATE	ACTIVITY
9/16/81	Plant visit to the Globe Manufacturing Company, Gastonia, N.C. - to observe the VOC emission control system for reaction-spun urethane fiber.
9/23/81	NAPCTAC Meeting.
9/30/81	Plant visit to the Tennessee Eastman Company, Synthetic Fibers Division, Kingsport, Tennessee, regarding the NSPS for the synthetic fibers industry.
10/28/81	Meeting at EPA/OAQPS with representatives of Tennessee Eastman Company to review their investigation of control device efficiencies.
11/5/81	Meeting at EPA/OAQPS with DuPont representative to elaborate on technical and economic issues discussed at the NAPCTAC meeting.
11/10/81	Meeting at EPA/OAQPS with representatives of Tennessee Eastman Company to review their concerns over the concept of enclosures on certain points along the cellulose acetate filtration tow process operation.
11/12/81	Meeting at EPA/OAQPS with representatives of Globe Manufacturing Company to review their concerns with the possible use of incineration as an alternate VOC emission control option.
12/1/81	Meeting at EPA/OAQPS with representatives of Tennessee Eastman Company to review capital cost estimates presented in the BID, safety concerns, and transfer of technology to acetate plants.
12/3/81	Meeting at EPA/OAQPS with representatives of Celanese Fibers Company to review certain technical aspects of the recommended standard as it would potentially affect their fiber manufacturing plants. Capital and annual operating costs were also reviewed.
12/11/81	Meeting at EPA/OAQPS with representatives of Tennessee Eastman Company to review additional information to support TE's previous NAPCTAC comment questioning the use of enclosures in the model plant for filter tow presented in the BID.

CHRONOLOGY (concluded)

DATE	ACTIVITY
1/26/82	Plant visit to the Tennessee Eastman Company, Synthetic Fibers Division, Kingsport, Tennessee, concerning the NSPS and resolution of the safety issue associated with the recommended use of enclosures on tow lines.
1/27/82	Plant visit to the DuPont acrylic fiber May Plant, Camden, South Carolina, to determine the technical aspects of the acrylic spin cell enclosures.
3/15/82	Emission evaluation tests conducted at the DuPont May Plant, Camden, South Carolina, to measure VOC concentration inside the spin cell enclosures.
4/ /82	Qualitative analysis of carbon beds conducted at the Globe Manufacturing Company plant, Gastonia, North Carolina.
4/ /82	Current draft Background Information Document mailed to synthetic fiber manufacturers and other interested parties for comment prior to proposal.

APPENDIX B

INDEX TO ENVIRONMENTAL CONSIDERATIONS

This appendix consists of a reference system which is cross-indexed with the October 21, 1974, Federal Register (39 FR 37419) containing the Agency guidelines for the preparation of Environmental Impact Statements. This index can be used to identify sections of the document which contain data and information germane to any portion of the Federal Register guidelines.

APPENDIX B

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

Agency Guidelines for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document
Background and summary of regulatory alternatives	The regulatory alternatives are summarized in Chapter 1, Section 1.1, pages 1-1 through 1-3.
Statutory basis for proposing standards	The statutory basis for the proposed standards is summarized in Chapter 2.
Relationship to other regulatory agency actions	The various relationships between the regulatory agency actions are discussed in Chapters 3, 7, and 9.
Affected industry	A discussion of the industry affected by the regulatory alternatives is presented in Chapter 3, Section 3.1. Details of the "business/economic" nature of the industry are presented in Chapter 9, pages 8-1 through 8-7.
Affected processes and facilities	The specific sources and processes to be affected by the regulatory alternative are discussed in Chapter 3, Sections 3.2 and 3.3, pages 3-23 through 3-48.
Availability of control technology	Information on the availability of control technology is given in Chapter 4, Sections 4.2, through 4.7, pages 4-2 through 4-32.
Environmental, energy, and economic impacts of regulatory alternatives	Various regulatory alternatives are discussed in Chapter 6, Sections 6.2 through 6-4, pages 6-6 through 6-43.
Environmental impacts	The environmental impacts of the various regulatory alternatives are presented in Chapter 7, Sections 7.2, through 7.4, pages 7-1 through 7-10.

Agency Guidelines for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document
Energy impacts	The energy impacts of the various regulatory alternatives are discussed in Chapter 7, Section 7-5, pages 7-10 and 7-11.
Cost analysis	Cost analysis of the various regulatory alternatives on model plants are discussed in Chapter 8, Sections 8.1 through 8.4, pages 8-1 through 8-21.
Economic impacts	The economic impacts of the various regulatory alternatives are presented in Chapter 9.

APPENDIX C
EMISSION MEASUREMENTS AND DETERMINATIONS

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APPENDIX C
EMISSION MEASUREMENTS AND DETERMINATIONS

C.1 INTRODUCTION

The methods and data used to aid in the development of baseline emissions of volatile organic compounds (VOCs) from synthetic fiber plants are presented in this appendix. Industry-wide emissions data were compiled through the use of various information gathering (methods resources) such as:

1) Section 114 requests for information;
2) Plant visits made to synthetic fiber manufacturers;
3) Testing programs for source emissions;
4) State air pollution control agenices; and,
5) Correspondence with industry representatives.

Emission source test data were obtained from two representative segments of the synthetic fibers industry. VOC emissions from the remaining segments of the industry subject to the new source performance standard were characterized by reducing the data supplied through the information gathering means listed above. The objectives of the source testing program were to:

1) Provide process mass emission data;
2) Determine the most appropriate and cost-effective testing methods for VOC emissions at synthetic fiber plants in preparation for later performance test specifications; and,
3) To detect the presence of acrylonitrile (ACN) in process exhaust gas streams.

C.2 DIRECT GAS-PHASE MEASUREMENTS

A brief discussion of the spinning process, spinning solvent, and type of fiber produced at each facility tested for VOC emissions is presented in this section. Typical acrylic fiber production operations were considered to be well represented by the two plants tested. These plants are identified as Facility A and Facility B.

C.2.1 Facility A

Facility A utilizes the dry spinning method of acrylic fiber production. The VOC measured was dimethylformamide (DMF). Gaseous process exhaust streams from fiber spinning and fiber texturizing operations were sampled. Table C-1 summarizes the test results at this facility.

A total of nine process exhaust gas streams were sampled and analyzed by various techniques. At each of the nine sampling locations, four sampling and analytical techniques were utilized to characterize the gas stream. These techniques included wet impingement, integrated bag, continuous monitoring, and silica gel tube adsorption as mentioned previously.

The continuous monitor was originally set up to be the primary method of collection and analysis since it could indicate process variations as they occurred. The wet impingement method and silica gel tube adsorption method were to be used to confirm the continuous data. In addition to solvent concentration, volumetric flow rate and moisture content of the process gas streams were determined on a daily basis by appropriate sampling techniques. The presence of acrylonitrile was screened on the same gas chromatograph column as was used to quantify solvent (DMF) concentration.

The test results of solvent concentration and solvent mass emission rates vary considerably between sampling techniques at the same test location. The concentrations and mass emission rate data were not taken at face value without considering the advantages and disadvantages of each method as implemented in the field. An example scenario used to compile the sampling and analytical data is shown below.

1) Calculate actual concentration level of solvent in the gas stream in units of parts per million (ppm).

a) Continuous monitor:

ppm solvent = ppm field x response factor

Table C-1. SUMMARY OF TEST RESULTS FROM FACILITY A

LOCATION	METHOD	CONCENTRATION (PPMV as DMF)	VOLUMETRIC FLOWRATE (DSCMM)	(DSCFM)	EMISSION RATES (lb DMF)/hr	(kg DMF)/hr	(lb DMF)/lb product
WDX	Wet Impingement[a]	---	487	17224	---	---	---
	Integrated Bag	5.95	487	17224	1.14	.52	6.21×10^{-5}
	Continuous Monitor[b]	5.44	487	17224	1.05	.48	5.72×10^{-5}
	Continuous Monitor[c]	60.4	487	17224	11.60	5.27	6.32×10^{-4}
	Total[d]	---	---	---	12.65	5.75	6.89×10^{-4}
	Silica Gel Tube	28.53	487	17224	5.48	2.49	2.98×10^{-4}
CRX	Wet Impingement	44.6	767	27096	13.5	6.14	7.35×10^{-4}
	Integrated Bag	11.93	767	27096	3.61	1.65	1.97×10^{-4}
	Continuous Monitor[a]	14.7	767	27096	4.45	2.02	2.42×10^{-4}
	Silica Gel Tube	36.26	767	27096	10.98	4.99	5.98×10^{-4}
SSX	Wet Impingement	238	12.8	453	1.20	.55	2.89×10^{-4}
	Integrated Bag	3.60	12.8	453	.02	.008	4.82×10^{-6}
	Continuous Monitor[a]	14.7	12.8	453	.07	.03	1.78×10^{-5}
	Continuous Monitor[b]	541	12.8	453	2.73	1.24	6.59×10^{-4}
	Total[d]	---	---	---	2.80	1.27	6.77×10^{-4}
	Silica Gel Tube	788	12.8	453	3.98	1.81	9.59×10^{-4}
	Condensate return water	1.6×10^{1} mg/mℓ	---	---	2.13	.97	5.13×10^{-4}
DMFX	Wet Impingement	170	29.5	1043	1.98	.90	4.78×10^{-4}
	Integrated Bag	4.03	29.5	1043	.05	.02	1.20×10^{-5}
	Continuous Monitor[a]	12.9	29.5	1043	.15	.07	3.61×10^{-5}
	Continuous Monitor[b]	238	29.5	1043	2.77	1.26	6.68×10^{-4}
	Total[d]	---	---	---	2.92	1.33	7.04×10^{-4}
	Silica Gel Tube	121	29.5	1043	1.41	.64	3.40×10^{-4}
DRX	Wet Impingement	598	276	9771	65.26	29.66	1.57×10^{-2}
	Integrated Bag	8.90	276	9771	.97	.44	2.37×10^{-4}
	Continuous Monitor[a]	3.98	276	9771	.43	.20	1.04×10^{-4}
	Continuous Monitor[b]	1265	276	9771	137.8	67.6	3.32×10^{-2}
	Total[d]	---	---	---	138.23	67.8	3.33×10^{-2}
	Silica Gel Tube	388	276	9771	42.34	19.25	1.02×10^{-2}

[a] Loss sample due to freezing.

[b] Gaseous phase seen at FID.

[c] Condensate liquid by HPLC analysis.

[d] Total is gaseous and condensate of continuous monitoring system.

Table C-1. SUMMARY OF TEST RESULTS FROM FACILITY A (Continued)

LOCATION	METHOD	CONCENTRATION (PPMV as DMF)	VOLUMETRIC FLOWRATE (DSCMM)	VOLUMETRIC FLOWRATE (DSCFM)	EMISSION RATES $\left(\frac{\text{lb DMF}}{\text{hr}}\right)$	EMISSION RATES $\left(\frac{\text{kg DMF}}{\text{hr}}\right)$	EMISSION RATES $\left(\frac{\text{lb DMF}}{\text{lb product}}\right)$
SCI	Wet Impingement	600.2	335	11830	79.4	36.1	5.06×10^{-3}
	Integrated Bag	123.15	335	11830	16.3	7.40	1.04×10^{-3}
	Continuous Monitor[a]	138.3	335	11830	18.29	8.31	1.16×10^{-3}
	Continuous Monitor[b]	8073	335	11830	1067	49.5	6.80×10^{-2}
	Total	---	---	---	1085.29	493.3	6.91×10^{-2}
	Silica Gel Tube	4753	335	11830	628	286	4.00×10^{-2}
SCX	Wet Impingement	2.77	337	11899	0.37	0.17	2.36×10^{-5}
	Integrated Bag	6.93	337	11899	0.92	0.42	5.86×10^{-5}
	Continuous Monitor[a]	7.81	337	11899	1.04	.47	6.62×10^{-5}
	Continuous Monitor[b]	6.5	337	11899	.86	.39	5.50×10^{-5}
	Total	---	---	---	1.9	.86	1.21×10^{-4}
	Silica Gel Tube	<.01	337	11899	---	---	---
PSX	Wet Impingement	481	135	4761	25.63	11.65	1.63×10^{-3}
	Integrated Bag	120.6	135	4761	6.43	2.92	4.09×10^{-4}
	Continuous Monitor[a]	9.22[c]	135	4761	.49	.22	3.12×10^{-5}
	Continuous Monitor[b]	1011	135	4761	53.87	24.49	3.43×10^{-3}
	Total	---	---	---	54.36	24.71	3.46×10^{-3}
	Silica Gel Tube	351	135	4761	18.70	8.50	1.19×10^{-3}
WSX	Wet Impingement	N.D.[d]	129	4545	N.D.	N.D.	N.D.
	Integrated Bag	20.05	129	4545	1.02	.46	N.D.
	Continuous Monitor[a]	9.16[d]	129	4545	.47	.21	N.D.
	Total	---	---	---	N.D.	N.D.	N.D.
	Silica Gel Tube	N.D.	129	4545	N.D.	N.D.	N.D.

[a] Gaseous phase seen at FID.

[b] Condensate liquid by HPLC analysis.

[c] Total is gaseous and condensate of continuous monitoring system.

[d] Not determined.

b) Wet impingement:

$$\text{ppmv solvent} = \frac{\text{weight of solvent sample}}{\text{volume of gas sample}}$$

2) Convert ppm concentration of gas stream to an emission rate in units of pounds per hour (lbs/hr).

lb/hr = ppm solvent x flow rate.

In general, the integrated bag method results may be disregarded at all of the test locations. After discussions with plant officials, and evaluation of test results, the analytical results obtained by this method are considered to be ureasonably low, and are invalid. Overall, the exhaust gas streams were relatively low in concentration. It is suspected that due to the solubility of DMF in water, the mass emission rate attributable to the water portion of the process streams was equal to or greater than the gaseous portion of the process exhaust stream. The concentration of DMF in the process water streams, recovered or exhausted, was measured routinely by plant personnel at several points.

Mass balance determinations centered on the spinning operations were based on historical plant data of process streams and measured emissions data on the gaseous process exhaust streams.

C.2.2 Facility B

Facility B utilizes the wet spinning method of acrylic fiber production. The VOC measured was dimethylacetamide (DMAC). Mass emission results were obtained for various component processing operations. Table C-2 summarizes the test results at Facility B.

Emission testing of the main spinning exhaust streams were monitored continuously over the duration of the test period. In addition, a screening of other gaseous exhaust vents was performed in order to determine if continuous monitoring should be conducted at these locations. Four separate sampling and analytical techniques were employed:

1) NIOSH Method S-254
2) FID continuous analyzer method
3) GC/FID Method
4) Wet impingement method.

Table C-2. SUMMARY OF TEST RESULTS FROM FACILITY B

Location	Source #	Method of Sampling and Analysis: NIOSH (ppmv as DMAC)	Wet impingement (ppmv as DMAC)	FIA (ppmv as DMAC)	OVA (ppmv as DMAC)	Source flow (DSCMM) Actual	Source flow (DSCMM) Estimated	Emission rate^a (lbs/hr) Actual	Emission rate^a (lbs/hr) Estimated
South stack	Spinning exhaust (1-16)	<0.1	9.4	9.9	--	4,778^b		21.19	
North stack	Spinning exhaust (17-30)	11.7^c	10.3^e	24.2	--	5,221^b		56.61	
								77.80 (Subtotal)	
Basement vent A	BV A	10.7	44.8	12.0	--	1,008		5.42	
Basement vent B	BV B	18.2	25.3	18.7	--	761		6.38	
Basement vent C	BV C	2.7	<0.1	5.6	--	1,594		4.00	
Basement vent D	B	--	--	--	--	--		Not operating	
								15.80 (Subtotal)	
Dope prep room vent A	RMV A	--	--	3.9	--	470	--	0.82	
Dope prep room vent B	RMV B	--	--	3.2	--	522	--	0.75	
Dope prep room vent C	RMV C	--	--	3.5	--	536	--	0.68	
								2.25 (Subtotal)	
Dope prep stack A	Room vent	--	--	--	--	--	--	--	0.06^f
Dope prep stack B	Room vent	--	--	1.2	--	110	--	--	
Dope prep stack C	Hood vent	--	35.7	65.0	--	--	110	3.20	
Dope prep stack D	Room vent	--	--	--	--	--	--	--	0.06^f
Dope prep stack E	Hood vent	--	--	1.3	--	--	110	0.06	
								3.38 (Subtotal)	
Crimper exhaust Type B	52(17-19)	--	--	1.4	0.8	120	--	0.08	--
	47(12-14)	--	--	--	1.1	--	120	--	0.06^g
	36(9-11)	--	--	--	1.1	--	120	--	0.06
Crimper exhaust Type F	45(23-26)	--	--	2.9	0.5	429	--	0.56	--
	34(27-30)	--	--	--	0.5	--	429	--	0.09^g
	44(1-4)	--	--	--	1.2	--	429	--	0.23^g
	54(20-22)	--	--	--	0.7	--	429	--	0.13^g
Crimper exhaust Type G	11(27-30)	--	--	--	0.5	186	429	0.04	--

(continued)

Table C-2. SUMMARY OF TEST RESULTS FROM FACILITY B (Continued)

Location	Source #	Method of Sampling and Analysis				Source flow (DSCMM)		Emission rate[a] (lbs/hr)	
		NIOSH (ppmv as DMAC)	Wet impingement (ppmv as DMAC)	FIA (ppmv as DMAC)	OVA (ppmv as DMAC)	Actual	Estimated	Actual	Estimated
Crimper exhaust Type H	57(25-26)	--	--	--	0.5	17	--	0.004	--
Crimper exhaust Type I	21(15-16)	--	--	--	1.1	--	26	--	0.01[g]
	20(17-20)	--	--	--	1.1	26	--	0.01	--
	10(21-24)	--	--	--	--	--	--	Not operating	
								[illegible] (subtotal)	
Exhaust fan type D	27(mc 16,17)	--	--	3.9	3.1	219	--	0.08	--
	9(mc 18,19)	--	--	--	--	--	--	Not operating	
	5	--	--	--	--	--	--	Not operating	
	46(mc 1)	--	--	--	--	--	--	Not operating	
	28(spin c)	--	--	--	--	--	--	Not operating	
	30(mc 2)	--	--	--	--	--	--	Not operating	
Exhaust fan	26(mc 3)[d]	--	--	--	3.3	--	219	--	0.08[f]
	39[d]	--	--	--	3.3	--	219	--	0.08[f]
	8(basement)	--	--	--	--	--	--	Not operating	
								[illegible] (subtotal)	
Spinning room ceiling exhaust	4	--	--	5.4	5.3	495	--	1.66	--
	3	--	--	4.1	1.9	--	495	--	[illegible][g]
	1	--	--	--	3.3	--	495	--	[illegible][g]
	2	--	--	--	5.5	--	495	--	[illegible][g]
								[illegible] (subtotal)	
Tow cooler type E	[illegible]	--	--	1.1	3.5	[illegible]	--	[illegible]	--
	[illegible]	--	--	1.1	--	--	[illegible]	--	[illegible]
	[illegible]	--	--	1.1	--	--	[illegible]	--	[illegible]
	[illegible]	--	--	1.1	--	--	[illegible]	--	[illegible]
	[illegible]	--	--	1.1	--	--	[illegible]	--	[illegible]
	[illegible]	--	--	1.1	--	--	[illegible]	--	[illegible]
	[illegible]	--	--	1.1	--	--	[illegible]	--	[illegible]
	[illegible]	--	--	1.1	--	--	[illegible]	--	[illegible]
Tow cooler	[illegible][g]	--	--	--	--	--	--	--	[illegible]
	[illegible]	--	--	--	--	--	--	--	[illegible]
	[illegible][g]	--	--	--	--	--	--	--	[illegible]
								[illegible] (subtotal)	

(continued)

Table C-2. SUMMARY OF TEST RESULTS FROM FACILITY B (Continued)

Location	Source #	Method of Sampling and Analysis				Source flow (DSCMM)		Emission rate[a] (lbs/hr)	
		NIOSH (ppmv as DMAC)	Wet impingement (ppmv as DMAC)	FIA (ppmv as DMAC)	OVA (ppmv as DMAC)	Actual	Estimated	Actual	Estimated
Roof exhaust	56	--	--	--	--	--	--	Not operating	
								104.35 (Total plant)	
Finishing stack	6 and 7	--	--	--	--	--	--	Not tested	
Condenser stack	59	--	--	--	--	--	--	Not tested	
Filter press hoods		--	--	--	--	--	--	Not tested	

[a] Based on FID concentration.

[b] These flows are based on pitot tube measurements, the remainder are based on anemometer readings.

[c] Average of two runs of 12.6 and 10.7.

[d] Operating periodically.

[e] Average of two runs of 17.4 and 3.2.

[f] Assume similar vents to have same flow and concentration.

[g] Assume similar vents to have same flow with a known concentration.

C.3 CALCULATION OF VOC EMISSIONS INDIRECTLY BY MATERIAL BALANCE

Performance test procedures do not necessarily require direct gas-phase measurement of VOC emissions. Instead, the procedures may involve a material balance to determine VOC emissions. The material balance is based on two facts. (1) Solvent can be lost from the process by only two routes: into the air (i.e., air pollutant emissions) or not into the air (nongaseous solvent losses); solvent loss minus nongaseous loss equals (solvent) VOC emissions. (2) Virgin solvent is fed to the affected facility to compensate or makeup for the solvent that is lost from within the facility during normal operation. Makeup solvent, however, does not necessarily equal solvent losses. Within an affected facility there is a finite amount of solvent contained in the tanks and pipes at any given time. This solvent inventory varies continuously, reflecting both losses from and additions to the system. Therefore, in relating makeup solvent to total solvent losses, an accounting must be made for solvent inventory variation. Total solvent losses equal makeup solvent plus solvent inventory change. Thus, the ability to accurately determine solvent makeup, solvent inventory, and nongaseous solvent losses allows the VOC emissions to be calculated:

VOC Emissions = Makeup Solvent - Nongaseous Solvent Losses -
Solvent Inventory Variation

Using this indirect or mass-balance method, emissions were determined for seven facilities, with available data of the type already routinely measured at these facilities. The determined emissions are presented in Table C-3.

Solvent feed. The term total solvent feed refers to the amount of solvent used to dissolve the polymer, and formulate the precipitation bath in the case of wet spinning. The material balance procedures allow solvent feed to be determined by one of the following three ways: (1) by direct measurement; (2) by measuring the amount of recovered solvent returned to the solvent feed holding tank and the makeup solvent (The solvent feed equals the sum of makeup solvent and recovered solvent corrected for inventory change in the solvent feed holding tank.); (3) from plant records of the amount of polymer feed and the solvent-to-polymer ratio of each spinning solution. Each of these

Table C-3. EMISSIONS AS DETERMINED FROM SOLVENT USE DATA FROM REPRESENTATIVE PLANTS

Month	VOC Emission (kg VOC/Mg Solvent Feed)						
	Plant A '79	Plant A '80	Plant B '80	Plant C '80	Plant D '80	Plant E '81	Plant F[c]
1	14.6	11.4		20.8	17.9	13.2	
2	8.2	10.7		17.4	15.0	7.7	
3	7.8	15.8		20.6	21.2	14.2	
4	11.5	12.8		20.9	16.0	6.6	
5	10.8	10.5		17.4	17.8	11.2	
6	14.2	14.8		15.2	20.5		
7	17.2	12.4		22.6	18.4		
8	15.5	11.2		20.1	22.9		
9	10.2	14.6		17.6	20.7		
10	8.6	9.5		17.2	17.0		
11	12.8	13.9		18.7	21.2		
12	17.0	10.0		19.3	19.3		
Year Average	12.4	12.3	14.6[a]	19.0	18.9	10.6[b]	

[a] No monthly data available.

[b] 5-month average.

[c] Information received from this plant concerning solvent use and calculated emissions contain apparent discrepancies. Plant officials were collecting additional data as of the time of publication in order to reconcile these discrepancies, but the new information will not affect any proposed standard(s).

three methods would yield an accurate determination of the amount of solvent feed to be used in the equation for determining VOC emissions.

Makeup solvent. This is the virgin solvent added to the affected facility to compensate for solvent lost during manufacture of the fibers. The material balance procedures require that the amount of makeup solvent introduced to the affected facility be measured and recorded.

Nongaseous losses. The term nongaseous losses means solvent losses from the process that are not released into the air. Nongaseous losses may occur as a result of disposing of or cleaning used filtration media, through runoff of excess fiber lubricant applied at the exit of the spin cell, as part of the steam condensate during crimping and heating operations, as residual solvent in the product, and as hydrolysis products during distillation of crude solvent/water solution. Data from several fiber plants indicate that these losses range from 6 to 13 kg per Mg of solvent feed, with most plants in the 10 to 13 kg range.

The nongaseous losses as presented here are based on industry-supplied data and EPA-conducted tests. The nongaseous losses for individual process points are not presented because of the sensitive and proprietary nature of this data. For example, the solvent residual content of the fiber at various process points in the production sequence cannot be revealed; the solvent removed from the fiber at various points is very sensitive; and the solvent that might be contained in a wash-water stream is also sensitive. The amount of solvent removed via specific non-gaseous routes is therefore not public information. Table C-4 summarizes nongaseous losses from six representative plants.

Table C-4. OVERALL NONGASEOUS LOSSES
(kg Solvent Losses/Mg Solvent Used)

Plant 1	13
Plant 2	6
Plant 3	6
Plant 4	12
Plant 5	10
Plant 6	10-13

Solvent inventory variation. The term solvent inventory refers to the amount of solvent contained in an affected facility at any given time. The majority of the solvent is contained in two locations. One is the solvent feed holding tank at the beginning of the process; this tank contains both recovered solvent and virgin makeup solvent. The other location is the crude solvent/water holding tank that precedes the solvent recovery distillation units; this tank contains the solvent that was used in processing the fiber, and captured for re-use. If no accounting is made for solvent inventory variation, erroneous calculated values for VOC emissions result. Table C-5 presents data from a representative plant that shows the ratio of inventory variation to total solvent feed when averaged over four different periods.

Table C-5. COMPARISON OF SOLVENT INVENTORY VARIATION WITH TOTAL SOLVENT FEED[a]

Averaging Period	Ratio[b] of Solvent Inventory Variation and Total Solvent Feed (kg Inventory Variation per Mg Solvent Used)
Year	±0.3
Month	±4.0
Week	±16.0
Day	±115.0

[a] Comparisons based on data from a representative plant.

[b] This ratio is computed by dividing the facility's maximum inventory variation by an average or typical value for the total solvent used during the averaging period.

The shorter the time period over which emissions are calculated, the greater the effect of solvent inventory variation. It is apparent that while the longer periods of averaging reduce the impact of this inventory variation, some adjustment must nevertheless be made to allow for this variation when computed on a monthly averaging period.

Data from several plants indicate that solvent inventory variation will almost certainly exceed the amount of makeup solvent on a daily or weekly basis. At the other extreme, the variation on a yearly basis would be negligible. Between these two extremes of a significant variation and a negligible variation is a monthly period for which the 5 years of data show that solvent inventory exceeds the amount of makeup solvent only about 10 percent of the time. Table C-6 compares the monthly solvent inventory variation at several plants with their monthly solvent makeup. This time period for determining emissions is attractive because monitoring and enforcement could be conducted on a relatively short-term basis, reducing the possibility of undetected long-term emissions.

Table C-6. MONTHLY SOLVENT INVENTORY CHANGE AS PERCENTAGE OF SOLVENT MAKEUP (%)

	PERCENT				
Month	Plant A '79	Plant A '80	Plant B '80	Plant C '80	Plant D '80
1	37.6	26.5	--	67.5	62.3
2	27.8	2.1	1.7	73.0	65.3
3	13.8	10.3	21.0	62.9	23.6
4	20.7	0.9	21.5	69.8	37.7
5	14.7	32.7	124.9	55.4	266.0
6	31.8	108.9	21.5	34.5	274.4
7	0.3	21.4	89.2	81.1	--
8	31.0	9.2	38.0	81.0	--
9	36.1	15.5	13.2	76.3	--
10	26.5	32.7	25.0	76.0	9.5
11	0.6	50.2	0.7	81.6	31.8
12	112.0	8.8	28.8	64.5	51.5
Year Average	4.9	4.4	0.7	72.8	15.8

NOTE: The above data clearly indicates that on a monthly basis the solvent inventory variation must be accounted for in material balance calculations of solvent emissions.

The following example has been included to demonstrate the impact of solvent inventory variation on the determination of total solvent losses. Figure C-1 presents a generalized solvent flow diagram for a typical solvent spun fiber production facility. The critical solvent flow streams are (M_1) the total solvent feed stream, (M_2) the recovered

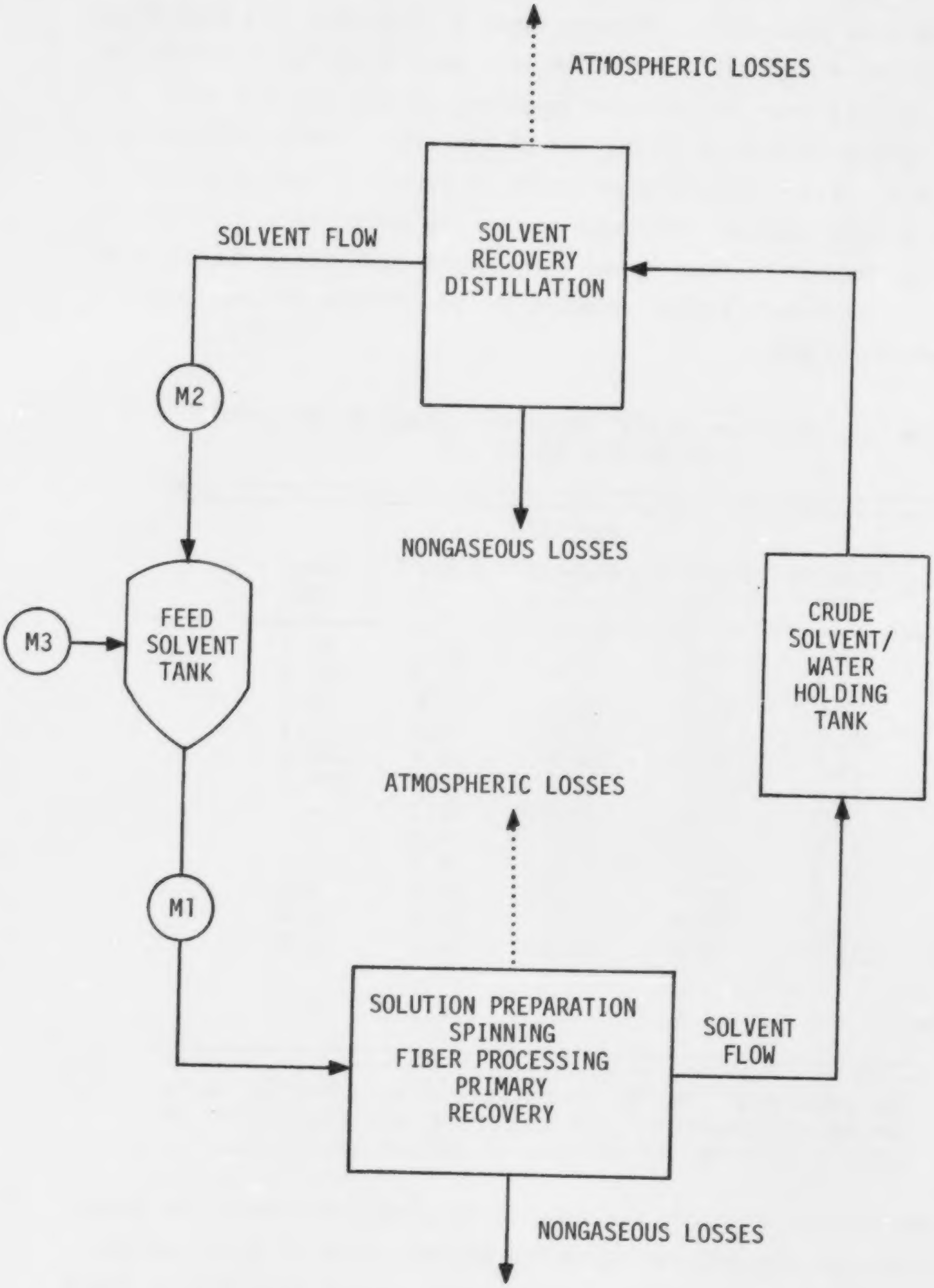
ATMOSPHERIC LOSSES
SOLVENT FLOW
SOLVENT RECOVERY DISTILLATION
M2
NONGASEOUS LOSSES
CRUDE SOLVENT/ WATER HOLDING TANK
M3
FEED SOLVENT TANK
ATMOSPHERIC LOSSES
M1
SOLUTION PREPARATION SPINNING FIBER PROCESSING PRIMARY RECOVERY
SOLVENT FLOW
NONGASEOUS LOSSES

Figure C-1. Solvent Inventory Impact on Solvent Loss Determination solvent stream, and (M_3) the makeup solvent stream. Three distinct cases are presented in the example in Table C-7, and within each case there are three illustrations of varying circumstances. Case 1 is the situation where total solvent inventory remains constant over the averaging period. Case 2 is the situation where there is a net increase in solvent inventory. Case 3 is the situation where there is a net decrease in the solvent inventory.

In summary, the following procedure is used to determine emissions per Mg of solvent feed. The amount of makeup solvent added during a given month is divided by the total amount of solvent feed measured during the same period. The resulting value is multiplied by 1,000 to arrive at a number that will represent solvent losses per Mg.

Nongaseous losses must be deducted, since this type of loss does not reflect solvent emissions. The value determined to represent nongaseous losses for the facility is subtracted from the number calculated in the paragraph above. As well, the solvent inventory variation is also subtracted, since it does not reflect actual VOC emissions. The value for inventory variation is calculated by subtracting the beginning solvent inventory from the ending inventory, (and indicating whether positive or negative) and dividing the difference by the amount of solvent feed measured during the month. This resulting value is then multiplied by 1,000 to arrive at a number that will represent variation per Mg of solvent feed. This number is then subtracted from the value for solvent losses per Mg to arrive at the monthly VOC emissions per Mg.

C.4 BASELINE EMISSIONS AND EMISSION FACTORS

Reported baseline emissions are derived from direct gas-phase measurements at selected facilities, emission data from State air pollution agency files, and also from material balance calculations. The material balance method of emission measurement is explained more fully in Section C-3. In order to establish the baseline emission values, it was necessary to evaluate the quality and reliability of the available data, and the degree to which the data was representative of typical existing conditions.

Because of the large number of emission points and the potential for fugitive emissions, emissions are not reported in pounds per hour

Table C-7. SOLVENT INVENTORY IMPACT ON SOLVENT LOSS DETERMINATION

Inventory Status	Solvent Inventory Change[a]			Metered Streams			Apparent Losses[b]		Apparent Feed[b]	Real Solvent Losses[c]
	Inv.	Feed Tank	Crude S/W Tank	M_1	M_2	M_3	M_1-M_2	M_3	$M_2 + M_3$	M_3 - Inv.
● Constant Inventory	0	0	0	5	4	1	1	1	5	1
	0	-1	+1	5	3	1	2	1	4	1
	0	+1	-1	5	5	1	0	1	6	1
● Increased Inventory	+1	+1	0	5	4	2	1	2	6	1
	+1	0	+1	5	3	2	2	2	5	1
	+1	+2	-1	5	5	2	0	2	7	1
● Decreased Inventory	-1	-1	0	5	4	0	1	0	4	1
	-1	-2	+1	5	3	0	2	0	3	1
	-1	0	-1	5	5	0	0	0	5	1

[a] The majority of the solvent is contained in two locations. One is the solvent feed holding tank at the beginning of the process; this tank contains both recovered solvent and virgin makeup solvent. The other location is the crude solvent/water holding tank that precedes the solvent recovery distillation units; this tank contains the solvent that was used in processing the fiber, and captured for re-use.

[b] Apparent loses and apparent feed are based on metered stream values (M_1, M_2, M_3) that have not been corrected for inventory change.

Corrections: a) If Makeup (M_3) and Recovered Solvent (M_2) are used to determine Total Solvent Feed (M_1), the change in the solvent feed tank must be subtracted from the total of $M_3 + M_2$.

b) If Solvent Feed (M_1) and Recovered Solvent (M_2) are used to determine Makeup (M_3), the change in the solvent feed tank must be added to the difference, $M_1 - M_2$.

[c] NOTE: In all cases the change in solvent inventory must be considered in determining real solvent losses.

(emission rate) or concentration (ppm). Rather, the emissions are related to production; that is, emissions per unit of fiber produced. This format is the same as used by most manufacturers and State air pollution agenices.

Baseline emissions, emission points, and exhaust gas characteristics of five representative plants are given in Table C-8.

C.5 DETERMINATION OF MAXIMUM PERFORMANCE TEST VARIATION

Although the preceding discussion seems to address most of the important variables and parameters that have a bearing on emission measurement by material balance, there is a further consideration to be addressed from an enforcement aspect. The period over which emissions are measured not only impacts on the value of the solvent inventory variation, but also on the variability in the actual emissions. That is, if all process parameters were to remain constant, there would still be some variability in emission measurements regardless of measurement method. This is true in this case as with all physical measurements. Any given measurement will differ from the long-term average by some expected amount that can be statistically determined. The size of this difference is in part dependent on the length of the averaging period over which emissions are measured. The baseline emission values represent the overall long-term (annual) levels that would be achieved under each alternative. No allowance has been made for normal variation in short-term emission levels. Tables C-9, C-10 and C-11 present a statistical analysis of the solvent use data gathered at six solvent spun synthetic fiber plants. Three averaging periods are examined: 1-month, 3-months, and 6-months. As can be seen from the analysis, the deviation of individual performance test results from the long-term average will vary inversely with the duration of the test period. The longer the performance test period, the less each individual emission determination will deviate from the long-term average emissions.

Statistical analysis of the monthly emissions values which were derived indirectly using solvent (mass-balance) measurements, indicates a significant month-to-month emission variation. No obvious temporal

Table C-8. BASELINE EMISSIONS

Plant Type	Solvent	Source Emissions			Exhaust Gas Characteristics[a]		
		Location[a]	Location	Quantity (kg)[b]	Flow (acfm)	Temp (°F)	Solvent Conc.(ppmv)
Acrylics/ Wet-Spun	DMAc	E1	Filtering/Dissolving	1	5,000[c]	80	25
		E2	Spinning/Washing	15	150,000[d]	120	100
		E3	Crimping/Drying	15	60,000	180	250
		E5	Cutting/Bailing Area	1	(Note 4)[d]	80	5
		E4	Primary Solvent Recovery Exhaust	3	--	--	--
		-	Miscellaneous Fugitives	5	--	--	--
Acrylics/ Dry-Spun	DMF	E1	Filtering	1	5,000[c]	100	10
		E2	Wash/Draw	2	200,000	100	10
		E3	Steaming/Drying	15	60,000	180	300
		E4	Base of Spin Cells	15	(Note d)	100	(Note f)
		-	Condenser Exhaust	1	--	--	--
		E5	Piddle and Waste System	6	1,000	80	1,000
		-	Miscellaneous Fugitives	5	--	--	--
Acrylic, Modacrylic/ Dry-Spun	Acetone	E1	Filtering/Dissolving	5	5,000	80	1,000[f]
		E2	Spin/Draw/Wash	57	(Note d)	80	1,000
		E3	Drying	55	15,000	140	2,300
		E4	Spin Cell Solvent Recovery Exhaust	23	--	--	--
Cellulose Acetate Filtration Tow/Dry-Spun	Acetone	E1	Filtering/Dissolving	2	5,000	80	1,000
		E2	Spin/Finish	60	(Note d)	80	--
		E3	Crimping	25	(Note d)	120	1,000
		-	Spin Cell Solvent Recovery Exhaust	28	--	--	--
		E4	Dryer Carbon Bed Exhaust	5	15,000-20,000	--	50
Cellulose Acetate Textile Yarn/Dry-Spun	Acetone	E1	Filtering/Dissolving	5	(Note d)	80	1,000
		E2,E3	Spinning/Winding	105	(Note d)	80	1,000
		-	Spin Cell Solvent Recovery Exhaust	30	--	--	--
		-	Miscellaneous Fugitives	5	--	--	--

[a] Locations as shown on appropriate diagrams in Chapter 6 representing baseline conditions.

[b] Kg VOC emissions per 1,000 kg polymer.

[c] Intermittent flow.

[d] Continuous fugitive emissions.

[e] Intermittent fugitive emissions into room air.

[f] Concentration variable.

Table C-9. NORMAL EMISSION VARIABILITY

Plant	Months of Data	Monthly Mean ($\bar{x}$) Emissions	Monthly Standard Deviation (σ)	Maximum Expected Monthly Emission Value At Confidence Level				
				90%	95%	97.5%	99%	99.5%
		(kg VOC/Mg Solvent)						
A	24	12.3	2.7	15.9	16.9	17.9	19.1	19.9
B	12	14.6[a]	--	--	--	--	--	--
C	12	19.0	2.1	21.9	22.8	23.6	24.7	25.5
D	12	19.0	2.4	22.3	23.3	24.3	25.5	26.5
E	5	10.6	3.3	15.6	17.6	19.8	23.0	25.8
F[b]	5							

[a] No monthly data available.

[b] Information received for this plant concerning solvent use and calculated emissions contain apparent discrepancies. Plant officials were collecting additional data as of the time of publication in order to reconcile these discrepancies, but the new information will not affect any proposed standard(s).

Table C-10. NORMAL EMISSION VARIABILITY

Plant	Months of Data[a]	Mean ($\bar{x}$) 3-Month Rolling Average	Standard Deviation for 3-Month Rolling Average (σ)	Maximum Expected 3-Month Emission Value At Confidence Level				
				90%	95%	97.5%	99%	99.5%
A	(24) 22	12.4	1.5	14.4	15.0	15.5	16.2	16.6
B	(12)	-	--	--	--	--	--	--
C	(12) 10	18.9	0.8	20.0	20.4	20.7	21.2	21.5
D	(12) 10	19.1	1.2	20.7	21.2	21.7	22.4	22.9
E	(5) 3	10.6	1.1	12.7	13.8	15.3	18.3	21.5
F[b]	(5)							

[a] Numbers in parentheses are the number of monthly data points, the numbers not in parentheses are the actual number of available 3-month average emission values.

[b] Information received from this plant concerning solvent use and calculated emissions contain apparent discrepancies. Plant officials were collecting additional data as of the time of publication in order to reconcile these discrepancies, but the new information will not affect any proposed standard(s).

Table C-11. NORMAL EMISSION VARIABILITY

Plant	Months of Data[a]	Mean ($\bar{x}$) 6-Month Rolling Average	Standard Deviation for 6-Month Rolling Average (σ)	Maximum Expected 6-Month Emission Value At Confidence Level				
				90%	95%	97.5%	99%	99.5%
A	(24) 19	12.6	0.6	13.4	13.6	13.9	14.1	14.3
B	(12)	-	--	--	--	--	--	--
C	(12) 7	18.9	0.4	19.5	19.7	19.9	20.2	20.4
D	(12) 7	19.3	0.8	20.5	20.9	21.3	21.8	22.3
E	(5)	--	--	--	--	--	--	--
F[b]	(5)	--	--	--	--	--	--	--

[a] Numbers in parentheses are the number of monthly data points, the numbers not in parentheses are the actual number of available 6-month average emission values.

[b] Information received from this plant concerning solvent use and calculated emissions contain apparent discrepancies. Plant officials were collecting additional data as of the time of publication in order to reconcile these discrepancies, but the new information will not affect any proposed standard(s).

pattern in the data was observed, nor could it be concluded that any of the variations were the result of improper operation and maintenance. Because of this variation, a plant's long-term average emissions might be less than the appropriate limit, but above the limit when measured over a shorter period, such as a month. With a monthly test period, an allowance could be added to the long-term levels to account for the maximum monthly emission variability. However, if a plant were able to consistently reduce its monthly emission variability, the facility's long-term emissions could significantly exceed the desired long-term levels, while at the same time meeting the adjusted short-term limit.

The 3-month and 6-month rolling averages were also evaluated. Comparing the single monthly averages with the 3-month and 6-month rolling averages shows that the deviations from the long-term mean are considerably less than the single monthly values.

C.6 TESTING OF SOLVENT VAPOR CONCENTRATIONS WITHIN RECOMMENDED ENCLOSURES

Industry representatives have commented that the enclosures as recommended for some of the control options may create unsafe conditions. Specifically, the concern was that the solvent vaporized within the enclosure could possibly reach explosive concentrations under some conditions, such as exhaust fan failure. Also, the transferability and economic feasibility of the recommended enclosures depend in part on the mass of solvent captured and collected by the enclosures.

In order to evaluate this system's features, enclosures at a plant that has used this technique for over 30 years were tested. The testing included measurement of enclosure solvent vapor concentration at many points and within enclosures where different products are spun. The points were chosen to develop a profile of the vapor concentrations in three axes: vertically, from front to back, and along the length of the spinning machine. Also, vapor concentrations were measured with one and with three doors opened to determine the effect of this action.

Because this data is not related to emissions, but is internal process information, the data is proprietary and exact values may not be released. This data, plus other information on spinning machine design, solvent characteristics, and ventillation criteria, however, allow certain conclusions to be reached. The conclusions revealed and confirmed the following: (1) The concentrations do not approach explosive levels at any point within the enclosures during normal operation. Also, the time necessary to achieve LEL were calculated for conditions of continued spinning machine operation, simultaneous exhaust fan failure, failure of operating personnel to follow normal safety procedures (such as not opening the enclosure doors to allow diffusion into the room) and presence of an ignition source. Calculations show that if all these conditions are met, the concentration will build from the starting point (as measured during these tests) to the lower explosive limit within 2 to 4 minutes, depending on the product, product denier, solvent used, and other variables. (2) Opening three or more doors will cause an immediate reduction in VOC concentration within the enclosure, due to diffusion into the room. (3) Where hot or warm solvent vapors exist, pockets of relatively higher vapor concentration may be generated within the enclosure, thus indicating the need for an effective flushing system. (4) In dry-spinning, there is an area immediately adjacent to the spin cell exit where high concentrations exist due to the "pumping" action of vapor out of the cell, but this area is quite small and probably contributes only a small portion of the overall solvent within the enclosure. If the spin cell exit were large, a proportionately larger contribution would be from the spin cell. It should be noted that this zone of relatively concentrated solvent vapor would exist irrespective of the use of enclosures. (5) No information was obtained in the course of the tests that would cast doubt on the efficacy and transferability of the enclosure systems to plants manufacturing other fiber types. Indeed, the plant tested has utilized enclosures on its spinning machines for over 30 years with no significant safety problems.

APPENDIX D

EMISSION MEASUREMENT METHODS

APPENDIX D

D.1 EMISSION MEASUREMENT METHODS

D.1.1 Background

The nature of emissions encountered during emission testing in the synthetic fibers industry are primarily organic emissions resulting from singular solvents used in the fiber production process. The chemical used as a solvent during the production of synthetic fibers is dependent upon the type of fiber produced and the production process utilized. The processes surveyed for testing under this program (NSPS development) utilized either acetone, dimethylformamide (DMF) or dimethyl acetamide as organic solvents. Other fiber production processes utilize different chemicals as a solvent, but were not selected for testing.[1] Organic emissions result from various segments of the fiber production process including dope preparation, fiber spinning, fiber drawing, fiber crimping, fiber drying, and fiber packaging. Emissions are primarily single solvents throughout the segments of the process. These emissions are captured by either room or building ventilation systems, or, by enclosing or hooding the process equipment and ventilating the enclosures. The ventilation systems can either discharge to a solvent recovery system or directly to the atmosphere, depending on the solvent content.

D.1.2 Field Test Experience

Initially three plants were selected as possible candidates for emission testing. Presurveys were conducted at all three candidate sites in order to gather information preliminary to the actual field test. Subsequent evaluation of the candidate sites led to the selection of two sites for field testing. The third test site was not tested because the plant's emission monitoring system used for process control provided adequate information for solvent emissions estimates. The emission testing was conducted at the two selected plants in the fall of

1980. Both plants tested produced acrylic fiber. One plant used a dry spinning process with dimethyl formamide as a solvent, and the other plant used a wet spinning process with dimethyl acetamide as a solvent. Emission test reports have been issued for the two test sites.[2,3] These reports describe in detail the test methods utilized, the testing problems encountered, and their resolution.

D.1.2.1 First Field Test. At the first field test site, flow sampling and analytical techniques were utilized to characterize the process exhaust gas streams for solvent concentration. These emission measurement methods included: (1) continuous hydrocarbon analyzers utilizing flame ionization detectors, (2) wet impingement utilizing a modified Method 4 with HPLC analysis, (3) NIOSH Method S-255 (absorption on silica gel tubes with GC/FID analysis), and (4) integrated gas bag samples with GC/FID analysis. The continuous hydrocarbon analyzers were the primary emission measurement method. The other methods were alternative methods used to confirm the continuous monitor data. Problems were encountered with the continuous analzyer method during the first test. The major problem was moisture condensation in the sample lines prior to the instrument and in the instrument itself. The moisture condensation scrubbed the solvent (DMF) from the gaseous phase of the exhaust stream due to the solubility of dimethyl formamide. Therefore, samples were collected in two phases, a condensed liquid phase, and a non-condensed gaseous phase.

Volumetric flow rate and moisture determinations were conducted on a daily basis by EPA Methods 1-4. Velocity traverses and volumetric flow rate determinations were performed according to criteria described in EPA Reference Method 1 (Sample and Velocity Traverses for Stationary Sources, Federal Register, 42 FR 41754, August 18, 1977) and EPA Reference Method 2 (Determination of Stack Gas Velocity and Volumetric Flow Rate, Federal Register, 42 FR 41759, August 18, 1977). EPA Reference Method 4 (Determination of Moisture Content in Stack Gas, Federal Register, 42 FR 41771, August 18, 1977) was utilized to volumetrically measure the moisture (H_2O) content of the flue gas streams.

D.1.2.2 Second Field Test. At the second field test site, the same four emission measurement methods were utilized with modifications. The continuous hydrocarbon analyzers again were the primary emission measurement system. The continous hydrocarbon analyzers were modified to alleviate problems observed during the first field test. These modifications include (1) removal of excess stainless steel components in the sampling system and replacement with Teflon® components and, (2) heating of sampling lines and instrument sampling chamber to prevent moisture condensation. These modifications were successful in alleviating problems encountered with the continuous hydrocarbon analysis during the first field test.

Volumetric flow rate determination and velocity traverses were performed according to EPA Reference Methods 1 and 2 where adequate duct siting requirements allowed. Those vents not measured by the pitot tube technique due to accessibility problems, and low flows were measured with a vane anemometer.

D.2 MONITORING SYSTEMS AND DEVICES

The continuous hydrocarbon analyzers utilized on non-continuous basis during the field tests are commercially available on an "off-the-shelf" basis. However, the application and proper operation of these as continuous monitor systems require considerable skill and previous experience. It should be noted that while continuous hydrocarbon monitors using flame ionization as a means of detection are commercially available, EPA has not developed specifications for continuous VOC analyzers. Various types of analyzers are used within the synthetic fibers industry and in similar industries for process control and emission monitoring.

The capital cost for a model system (FID-type) used to monitor process emissions will cost approximately $12,000 per installed monitoring unit. Operating cost are approximately $6,000 per year.

D.3 PERFORMANCE TEST METHOD

There are two methods of determining VOC emissions from synthetic fiber manufacturing plants: direct measurement of emissions with standard instruments and techniques, and indirect determination by mass balance.

D.3.1 Direct Determination

Draft Reference Method 25A - Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer is the recommended performance test method for VOC at synthetic fiber manufacturing facilities.

EPA Reference Method 1 and 2 are the recommended performance test methods for velocity and volumetric flow rate determination.

EPA Reference Methods 3 and 4 are recommended performance test methods when and where necessary to measure emissions streams with significant moisture content and non-air based flue gas.

D.3.1.1 Cautions. Testing experience has shown that special care is necessary to prevent condensation when utilizing a flame ionization analyzer for measuring organic solvents at synthetic fiber facilities. Performance of this method should not be attempted by persons unfamiliar with the performance characteristics of the flame ionization detector, nor by those who are unfamiliar with source sampling. Particular care should be exercised in the choice of equipment and operation in potentially explosive atmospheres.

The appropriate conditions for locating the site for velocity measurement must meet the specifications prescribed in EPA Reference Method 1. The range of the volumetric flow must be within the prescribed limits of EPA Reference Method 2. Otherwise, alternative volumetric flow rate measurements must be implemented.[6]

D.3.1.2 Costs. The cost of conducting the recommended test series is estimated to range between \$5,300 and \$6,600, plus travel time, travel costs, and subsistance. The performance test series would include three 4-hour test runs on a single source. At the two sites tested by EPA, the number of sources tested were 9 and 55. Therefore, a complete emission test is estimated to cost \$47,000 to \$363,000 and require about 20 to 25 days.

If more than one source would be tested at a particular plant, economies of scale may reduce the estimated cost per test series by 10 to 20 percent.

D.3.2 Indirect Determination

An alternative to direct measurement of VOC emissions from synthetic fiber plants has also been developed. The method of determining emissions indirectly using mass balance is based on the fact that makeup solvent equals solvent loss in all cases. By definition, the total solvent loss is via two routes; air emissions and non-gaseous (all other) losses. The accurate measuring of solvent makeup rates coupled with knowledge of non-gaseous losses provides a basis for determining air emissions relative to total solvent use and/or total fiber produced. In other words, if the makeup rate and the non-gaseous loss rate are known, the difference between the two would reveal air emissions.

D.3.2.1 Determination of Non-Gaseous Losses. Rather than require each facility to measure and report non-gaseous losses to the enforcing agency, it was determined that a more straightforward approach would be to assign a figure for non-gaseous losses to all affected facilities. That is, each affected facility would be allowed a given value for non-gaseous losses as determined by observations at existing plants. This determined value would be used uniformly at all affected facilities unless a company is able to demonstrate to the satisfaction of the enforcing agency that their fiber manufacturing process involves greater non-gaseous losses.

D.3.2.2 Format Variations. The specific amount of information required to determine air pollution emissions through use of the indirect determination varies to some extent with the format of a recommended standard. If, for example, an emission limitation is based on the amount of fiber produced (Kg VOC/1000 Kg fiber product) then only the amount of makeup solvent would be directly monitored as a requirement of the standard. This quantity would be related to the amount of fiber produced; the non-gaseous losses would also be given in terms of solvent mass per unit of fiber produced. Air emissions could then be determined.

If the standards is developed on the basis of VOC emissions per unit of solvent used (Kg VOC/1000 Kg solvent) then additional monitoring requirements would be necessary. The total amount of solvent used in dissolving the polymer would be metered as a requirement of the standard as well as the amount of makeup solvent. In this case non-gaseous losses would be given in terms of solvent mass per unit of total solvent-use. Air emissions could then be determined.

D.3.2.3 Costs. The cost of conducting the indirect determination is considerably less than that of the direct monitoring. The continuous solvent flow monitors that would be required for a standard based on indirect performance testing are commercially available on an "off-the-shelf" basis. Application, installation, and proper operation of these continuous totalizing flow meters would not require a level of skill or experience above that now practiced at existing synthetic fiber manufacturing facilities. The capital cost for the totalizing flow meters is about $1,000 to $3,000 per installed monitoring unit. Annual operating costs are estimated to be less than $1,500 to $2,000 per year, not including any data reduction or reporting.

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APPENDIX E: METHODOLOGY FOR COMPUTING WEIGHTED AVERAGE COST OF CAPITAL FOR PRODUCERS OF ACRYLIC AND MODACRYLIC AND CELLULOSE ACETATE AND TRIACETATE FIBERS

APPENDIX E: METHODOLOGY FOR COMPUTING WEIGHTED AVERAGE COST OF CAPITAL FOR PRODUCERS OF ACRYLIC AND MODACRYLIC AND CELLULOSE ACETATE AND TRIACETATE FIBERS

The weighted average cost of capital (WACC) for a firm is the cost of financing all current investments. The cost of capital is constructed from the cost of long-term debt, the cost of preferred stock, and the cost of common stock, the three financial instruments available to the firm. The cost of capital is a weighted average of the costs of these three components. The cost of each is weighted by the relative amount of each in the total capitalization of the firm (the values of the three sum to the value of total capitalization). The inherent assumption is that the firm is currently at an optimal (cost-minimizing) mix of debt, preferred stock, and common stock in its capital structure. Thus, future investments will be financed by a mix of long-term debt, preferred stock, and common stock equivalent to that evidenced in the firm's most recent balance sheet data.

The weighted average cost of capital can be used to determine the attractiveness of an investment opportunity. Assuming profit-maximizing behavior, a firm would not undertake an investment if the weighted average cost of capital of the firm exceeded the estimated rate of return associated with the investment. In this sense, the weighted average cost of capital can be employed as a discount rate to estimate the net present value of an investment opportunity. A profit-maximizing firm will invest only in a project with a positive net present value--one in which discounted cash inflows exceed discounted cash outflows over the lifetime of the project.

The application of the weighted average cost of capital as a discount rate to assess net present value was used to analyze the attractiveness of the model plants as investment opportunities for producers of acrylic and modacrylic and cellulose acetate and triacetate fibers. For this purpose, a weighted average cost of capital was calculated for each producer. The firm-specific weighted average costs of capital were then averaged to obtain a weighted (rather than simple) average cost of capital for the industry. The weighting scheme for the industry's cost of capital was to weight each firm's WACC by its share of the total capitalization of all firms.

The firms identified as domestically owned producers of acrylic and modacrylic and cellulose acetate and triacetate fibers were American Cyanamid, Celanese, Eastman Kodak, E. I. du Pont de Nemours, Monsanto, and Avtex Fibers. The data required to estimate a weighted average cost of capital for the firm were not available for two of the firms, Eastman Kodak and Avtex Fibers. Therefore, the industry weighted average cost of capital was calculated from weighted average costs of capital for American Cyanamid, Celanese, E. I. du Pont de Nemours, and Monsanto. The nominal weighted average cost of capital for the industry was calculated to be 10.95 percent in 1980, or 4.74 percent in real terms.

As mentioned, the firm-specific weighted average cost of capital was defined as:

$$WACC = w_1 Kd + w_2 Kp + w_3 Ke, \qquad \text{(E-1)}$$

where

WACC = weighted average cost of capital

w_1 = percentage of total capitalization comprised of long-term debt

w_2 = percentage of total capitalization comprised of preferred stock

w_3 = percentage of total capitalization comprised of common stock

Kd = cost of (required rate of return on) long-term debt

Kp = cost of (required rate of return on) preferred stock

Ke = cost of (required rate of return on) common stock (equity)

The costs of the three financial instruments (Kd, Kp, Ke) are the aftertax rates of return required to pay interest on long-term debt, preferred stock dividends, and common stock dividends, respectively. These are nominal rates of return that embody inflationary expectations. The effect of inflation was not removed until after calculating the industry WACC.

The weights for the three types of financial instrument (percentage of each in the total capitalization of the firm) were taken from the Value Line Investment Survey.1 The percentages were those evidenced in the firms' balance sheets in mid-1980.

Preferred stock was evident in the balance sheets of three of the firms (Celanese, 5 percent, Du Pont, 3 percent, and Monsanto, a small negotiable amount). All of these firms had retired portions of their preferred stock in the last year.2 Also, only infrequently do firms issue such stock today. Therefore, it was assumed that these firms would not issue preferred stock to finance new investment. Rather, it was assumed that the amount of capital raised previously by issuing preferred stock would today consist of long-term debt and common stock, in the same proportion that long-term debt and common stock are currently employed by each firm to raise capital.

Thus, equation E-1 reduces to

$$\text{WACC} = w_1 + \frac{w_1}{w_1 + w_3} \text{ v } w_2 \quad \text{Kd} + w_3 + \frac{w_3}{w_1 + w_3} \text{ v } w_2 \quad \text{Ke} \qquad \text{(E-2)}$$

In the first term, the required rate of return on long-term debt (Kd) is defined as

$$\text{Kd} = (1-\text{T}) * \text{YIELD}, \qquad \text{(E-3)}$$

where

Kd = the required rate of return on long-term debt

T = the marginal tax rate of each firm

YIELD = the yield on each firm's risk class of debt

An estimate of the firm's risk class of debt was obtained from Moody's Industrial Manual.3 Moody's rates firms according to the riskiness of their bonds and presents yields by risk class. The yields by risk class of debt for 1980 as estimated by Moody's Investor Service are:

Ratings class	Yield (percent)
AAA	11.94
AA	12.50
A	12.89
BAA	13.67

As would be expected, as the riskiness of one firm's bonds relative to other firms' bonds increases, the rate of return on the firm's bonds demanded by investors increases. For all firms, T (the tax rate) was estimated to be 49 percent, reflecting the current Federal marginal tax rate for businesses, adjusted to include State taxes (which are computed after deducting Federal taxes).

In the second term, the required rate of return on common equity was calculated using the capital asset pricing model. This model defines the required rate of return on common equity to be

$$Ke = Rf + b * (Rm - Rf) \qquad \text{(E-4)}$$

where

Ke = the required rate of return on common equity

Rf = risk-free rate

Rm = return on the market portfolio

b = the firm's 1980 beta, taken from the Value Line Investment Survey

The rate of return on a firm's common stock is greater than the risk-free rate of return. The magnitude of the risk premium is determined jointly by the difference between the market portfolio rate of return and the risk-free rate, and the way in which the return on the firm's stock varies with the return on the market portfolio (the firm's beta).

Rf, the risk-free rate, was estimated by averaging the yields reported for each month of 1980 on U.S. Treasury bonds due or callable in 10 years or more.4 Rm was estimated by averaging the yields reported for each month of 1980 on AAA corporate bonds.5 Statistical confidence intervals (99.9

percent) were found around the Rm - Rf term, the Beta coefficient of that term, and the Rf term, and used to produce a range of Ke's for each firm.

WACCs for each firm were thus calculated. To obtain the industry WACC, each firm's WACC was weighted by its contribution to the sum of all four firms' total capitalization. Capitalization was computed from line entries on each firm's 1980 balance sheet, as reported by Moody's Industrial Manual, 1980. The nominal WACC for the synthetic fibers (acrylic, modacrylic, cellulose acetate, and cellulose triacetate producers) was calculated to lie between 9.87 and 10.95 percent.

All costs reported in Chapter 8 of the Background Information Document are mid-1980 dollars. Therefore, to discount these costs over the life of the plant for net present value and implicit price calculations, it is necessary to use a WACC for the industry that does not contain a component that reflects inflation.

To remove the component of inflation from the nominal WACC, hence estimating a "real" WACC, it was first necessary to estimate that component of the risk-free rate that compensates for the time value of money, and to assume that the residual of the risk-free rate was the component that reflected inflation. The EPA assumed that investors demanded 3.0 percent return in 1980 to compensate them for the time value of money (that is, because one invests today, one can not consume until some later day). A confidence interval was then found around the average of the yields reported monthly for 3-month Treasury bills.6 The 3.0 return was subtracted from the endpoints of this range, yielding a range for the estimate of inflationary expectations of 6.21 to 11.01 percent.

The endpoints of the range of estimates for inflationary expectations were then subtracted from the endpoints of the range of estimates for the industry's nominal WACC. Four estimates of the industry's "real" WACC resulted. Of these, the highest real WACC was chosen for the net present value and implicit price calculations. The highest estimate of the real industry WACC, 4.74 percent, was chosen because this estimate results in the most adverse impact on producers and consumers and hence is the "worst case" scenario.

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APPENDIX F

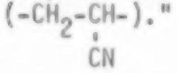
GLOSSARY

GLOSSARY

Accelerators - compounds that speed cross-linking and curing in elastomers.

Acetate and Triacetate Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is cellulose acetate. Where not less than 92 percent of the hydroxyl groups are acetylated, the term triacetate may be used as a generic description of the fiber." Raw materials: wood pulp, acetic anhydride, and acetic acid.

Typical trade names: Arnel^R, Avisco^R, Celanese^R, Estron^R.

Acrylic Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight of acrylonitrile units  $(-CH_2-\underset{CN}{\underset{|}{CH}}-)$."

Raw materials: mainly acrylonitrile.

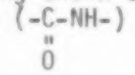
Typical trade names: Acrilan^R, Creslan^R, Orlon^R, Zefran^R.

Activators - substances required to achieve the full effects of some accelerators.

Anidex Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 50 percent by weight of one or more esters of a monohydric alcohol and acrylic acid, $CH_2=CH-COOH$." Anidex fibers are not commercially produced.

Antioxidants - substances that prevent oxidative attack of polymers especially at double bonds.

Antistatics - additives that imigrate to the finished polymer surfaces and reduce its tendency to accumulate static electric charges.

Aramid fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is a long-chain synthetic polyamide in which at least 85 percent of the amide  $(-\underset{O}{\underset{\|}{C}}-NH-)$ linkages are attached directly to two aromatic rings." Raw materials: m- and p-phenylene diamine and iso- and terephthaloyl chloride.

Typical trade names: Kevlar^R, Nomex^R.

Azlon Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is composed of any regenerated, naturally occurring proteins." Although small quantities of protein-based fibers are still produced in Poland, commercial production in the United States stopped in 1958.

Bicomponent Fibers - fibers obtained by spinning two polymers of the same or different generic types into a single fiber.

Biconstituent Fibers - fibers containing minute tiny fiber chains (fibrils) of one polymer generic type dispersed in a matrix of a second polymer generic type so that each fibril is parallel to the longitudinal axis of the fiber.

Bleaching - the treatment of textile fibers, yarns, or cloth to destroy the natural coloring matter and leave the material white. Hydrogen peroxide is a widely used bleaching agent.

Blends and Mixtures - blends are yarns containing two or more chemically or physically dissimilar fibers. Mixtures are fabrics containing chemically or physically dissimilar yarns, e.g., a fabric in which the warp yarns are rayon and the filling yarns are cotton. Most cotton-polyester durable-press items are blends.

Bonded Fabrics - fabrics made by sealing two fabrics together back to back with an adhesive.

Bulked Fibers - fibers that have been crimped, curled, or looped, and occupy a greater volume than in the unbulked state. Bulked continuous filament yarns are frequently termed BCF yarns. (See also Textured Yarn.)

Catalysts - materials added to reactors to accelerate the polymerization process.

Cellulosic Fibers - fibers based on regenerated cellulose or derived from cellulose.

Coagulants - substances (salts or acids) used to precipitate polymer solids out of emulsions or latexes.

Colorants - refers to pigments in plastics and elastomers and dyes in fibers.

Combing - a method of removing short fibers and foreign matter from cotton or wool stock by processing it through a series of needles (or combs).

Compacting - a mechanical compressive shrinkage operation.

Crimping - a process in which waves are mechanically set into fibers to help simulate properties of natural fibers.

Decating - using a combination of steam and pressure to give a soft hand and feel to the fabric.

Delusterants - fiber finishing additives used to dull the surfaces (usually clays or barium sulfate).

Denier - the weight in grams of 9,000 meters of a yarn or filament, e.g., 9,000 meters of 100-denier yarn weighs 100 grams. The lower the denier, the finer the yarn. A 50-denier yarn is twice as fine as a 100-denier yarn.

Dispersants - substances added to water to promote uniformity and small size to monomer droplets in reactors, especially in suspension polymerization for fibers.

Dope - a term used for the polymer spinning solution in acrylic fiber manufacture.

Drying - the process in which extruded fibers are charged into a vessel or unit for the purpose of reducing the moisture or solvent content of the product fiber using a heated gas stream. The unit includes foundations, superstructure, material charger systems, exhaust systems, and integral control systems.

Dry Spinning - a process in which filaments emerging from the spinneret are solidified by being dried in warm air. This process is used in the production of acetate, acrylic, modacrylic, spandex, triacetate and vinyon.

Emulsifiers - soaps and detergents used to produce stable mixtures of monomers in water before polymerization.

Extenders - foreign substances used to fill or extend a polymer as oils in NBR and bauxite in ABS.

Extension - a drawing process that forces polymer through regions of high temperature and pressure with great shear; melting and compacting the polymer to a desired final cross section.

Fiberfill - a fiber which is designed specifically for use as a filling material. Usually such a fiber is highly crimped to add bulk, and is resilient so it will not mat. Polyester fiber is most commonly used as fiberfill in such items as furniture, pillows, and quilted linings.

Fibers - The fundamental unit used in the fabrication of textile yarns and fabrics having a length at least 100 times its diameter and usually having a definitely preferred orientation of its crystal unit cells with respect to a specific axis.

Filament - a man-made continuous strand of yarn of near infinite length.

Filament Yarn - a yarn composed of two or more continous filaments assembled or held together by little or no twist. Filament yarn is often called continuous filament yarn, multifilament yarn, or yarn; the latter term is not to be confused with spun yarn.

Flame Retardants - materials used as coatings on fibers to reduce their flammability.

Fluorocarbon Fibers - FTC generic definition: A manufactured fiber in which the fiber-forming substance is a long-chain synthetic polymer composed of ethylene, propylene, or other olefin units in which some or all of the hydrogen atoms attached to the carbon chain have been replaced by fluorine or fluorinated alkyl groups. Raw materials: tetrafluorethylene and fluorinated ethylene-propylene copolymers.

Typical trade name: Teflon^{R}.

Glass Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is glass." Raw material: special glass.

Typical trade names: Beta^{R}, Fiberglas^{R}, PPG^{R}

Hand - a term used to describe a composite of textile properties such as flexibility, resiliency, softness or harshness, texture, and warmth.

Heat Sensitivity - the property of a material which causes softening, shrinking, melting, or discoloration when heat is applied.

Industrial Fibers - fibers that are often characterized by their high tensile strength, used to make such products as bagging, cordage, paper and tape reinforcing, and rope.

Inhibitors - additives used with monomers to prevent auto-polymerization.

Initiator - an agent used to initiate polymerization in a reactor.

Knit Fabric - a fabric produced by a method of interlooping one or more yarns. (i.e., flat knitting, circular knitting, warp knitting, weft knitting, single knit, or double knit)

Lubricants/Mold Release - oils or similar substances that are applied to fibers to improve wearability and to molding resins for mold release.

Man-made Fibers - any fiber not found in nature. These include cellulosics, which are partially synthetic, and wholly synthetic fibers, which are composed of materials made entirely by chemical synthesis.

Melt spinning - a process in which the fiber-forming substance is melted for extrusion and hardened by cooling. Nylon, olefin, polyester, aramid and glass are produced by the melt spinning process.

Mercerizing - a process given to cotton yarns and fabrics to increase luster, improve strength and dyeability. Treatment consists of impregnating fabrics with cold concentrated sodium hydroxide solution.

Metallic Fibers - FTC generic definition: "A manufactured fiber composed of metal, plastic-coated metal, metal-coated plastic, or a core completely covered by metal." Raw materials: aluminum, stainless steel, and various plastics (such as Mylar^{R}, polyester film or cellulose acetate butyrate).

Typical trade names: Brunslon^{R}, Lurex^{R}, Metlon^{R}

Mixtures - see definition for "blends."

Modacrylic Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of less than 85 percent but at least 35 percent by weight of acrylonitrile units $(-CH_2-\underset{CN}{CH}-)$, except where it qualifies as rubber or anidex." Raw materials: acrylonitrile and vinyl chloride (or other comonomers).

Typical trade names: Verel^R, Elura^R.

Mold Release - see definition for "lubricants."

Monofilament - a single filament of man-made fiber of sufficient size to function as a yarn in normal textile operations.

Natural Fibers - a class of fibers with an animal, vegetable, or mineral origin (e.g., wool, cotton, and asbestos, respectively).

Noncellulosic Fibers - fibers composed of organic materials that are made entirely by chemical synthesis.

Nonwoven Fabrics - fabrics consisting of a web of fibers held together by chemical bonding, fusion, or mechanical joining.

Novoloid Fibers - FTC generic definition: "A manufactured fiber containing at least 85 percent by weight of cross-linked novalac." Raw materials: phenol and formaldehyde.

Typical trade name: Kynol^R.

Nylon Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is a long-chain synthetic polyamide in which less than 85 percent of the amide $(-\underset{\underset{O}{\|}}{C}-NH-)$ linkages are attached directly to two aromatic rings." Raw materials: hexamethylenediamine and adipic acid (for nylon 66); caprolactam (for nylon 6).

Typical trade names: Antron^R (for nylon 66); Caprolan^R (for nylon 6).

Nytril Fibers - FTC generic definition: "A manufactured fiber containing at least 85 percent of a long-chain polymer of vinylidene dinitrile $(-CH_2-C(CN)_2-)$ where the vinylidene dinitrile content is no less than every other unit in the polymer chain." Raw materials: Vinylidene dinitrile (vinylidene cyanide) and a vinyl ester (such as vinyl acetate or vinyl propionate).

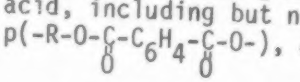
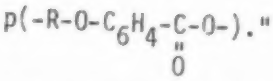
Nytril fibers are not commercially produced.

Oil Extending - use of hydrocarbon oils to extend elastomers. Oils are added as emulsion to the latex before coagulation.

Olefin (Polyolefin) Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight of ethylene, propylene, or other olefin units, except amorphous (non-crystalline) polyolefins qualifying as rubber." Raw materials: propylene, ethylene.

Typical trade names: Herculon^R, Marvess^R, Vectra^R.

Orientation - see definition for "stretching."

Polyester Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight of an ester of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalate units  $p(\text{-R-O-}\underset{\overset{\|}{O}}{C}\text{-}C_6H_4\text{-}\underset{\overset{\|}{O}}{C}\text{-O-})$, and para-substituted hydroxybenzoate units,  $p(\text{-R-O-}C_6H_4\text{-}\underset{\overset{\|}{O}}{C}\text{-O-})$."

Raw materials: dimethyl terephthalate, terephthalic acid, and ethylene glycol.

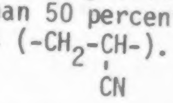
Typical trade names: Dacron^R, Fortrel^R, Kodel^R, Trevira^R.

Polyolefin Fibers - see definition for "olefin fibers."

Rayon Fibers - FTC generic definition: "A manufactured fiber composed of regenerated cellulose, as well as manufactured fibers composed of regenerated cellulose in which substituents have replaced not more than 15 percent of the hydrogens of the hydroxyl groups." Raw materials: wood pulp, sulfuric acid, sodium hydroxide, carbon disulfide, and zinc sulfate. In some countries outside of the Unites States, other cellulosic raw materials (e.g., straw) may be used.

Typical trade names: Avril^R, Beaunit^R, Enka^R, Fiber 40^R, Polynosic^R.

Retardants - chemicals applied topically to fabrics or in-situ to fibers to retard burning, etc.

Rubber - FTC generic definitions: "A manufactured fiber in which the fiber-forming substance is comprised of natural or synthetic rubber, including the following categories: (1) a manufactured fiber in which the fiber-forming substance is a hydrocarbon such as natural rubber, polyisoprene, polybutadiene, copolymers of dienes and hydrocarbons, or amorphous (non-crystalline) polyolefins, (2) a manufactured fiber in which the fiber-forming substance is a copolymer of acrylonitrile and a diene (such as butadiene) composed of not more than 50 percent but at least 10 percent by weight of acrylonitrile units  $(\text{-}CH_2\text{-}\underset{\underset{CN}{|}}{CH}\text{-})$.

Solution Dyeing - the addition of pigment to the polymer before extrusion through the spinneret, which results in the distribution of color throughout the fiber.

Solution Polymerization - monomers are dissolved in hydrocarbon or inorganic/aqueous solvents during polymerization. Used primarily for acrylic fibers production.

Spandex Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is a long-chain synthetic polymer comprised of at least 85 percent of a segmented polyurethane." Raw materials: diisocyanates, polyester or polyether polyols, and diamines. Typical trade names: Glospan^R, Lycra^R, Numa^R.

Spinneret - a spinneret is used in the production of all man-made fibers; where by liquid is forced through holes. Filaments emerging from the holes in the spinneret are hardened or solidified. The process of extrusion and hardening is called spinning.

Spinning - describes both (1) the twisting together of short fibers into continuous strands called spun yarn, and (2) the manufacture of a fiber by extruding a liquid through a spinneret.

Spun Yarn - yarn made from staple fibers that have been twisted together into a continuous strand.

Staple - lengths of fiber made by cutting man-made fiber tow into short (1- to 5-inch) and usually uniform lengths, which are subsequently twisted into spun yarn.

Stretching and Orientation - a process done while the fibers are hardening, or after they have been hardened, thus reducing the fiber diameter, or denier, and causing the molecules in the fiber to arrange themselves into a more orderly pattern. In a given fiber type, the strength increases and the fiber's ability to stretch without breaking decreases as the pattern of the molecular arrangement becomes more orderly, or better oriented. A wide range of strength/stretch combinations may be produced in this way.

Suspension Polymerization - polymerization with monomers suspended in an aqueous media. The iniator is dissolved in the monomer phase with similar kinetics to the bulk process.

Tenacity - a measure of the resistance a fiber has to stress at a specified elongation in the fiber. Breaking tenacity is most commonly considered and is measured by the stress (in grams) required to elongate a fiber to the breaking point.

Textile Fibers - fibers that can be spun into yarn and made into apparel or home furnishing fabrics by a variety of methods, including weaving, knitting, felting, and braiding.

Textured Yarn - yarn that has been mechanically treated to increase stretch, bulk, or covering power. Thermo-plastic yarns are textured by changing the shape of the fiber to introduce crimps, coils, loops, or other fine distortions along the length of the filament yarn, then heat-setting the changed state.

Tow - a collection of many parallel, continuous filaments, without twist, which are grouped together in a rope-like form having a diameter of about one-quarter inch. The advantage of tow is that spun yarn mills can cut tow into staple of any desired length, thereby keeping low inventories of different lengths of precut staple.

Triacetate Fibers - see definition for "acetate fiber."

Vinal Fibers - FTC generic definition: "A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 50 percent by weight of vinyl alcohol units $(-CH_2-CHOH-)$ and in which the total of the vinyl alcohol units and any one or more of the various actual units is at least 85 percent by weight of the fiber." Raw materials: vinyl chloride and vinyl acetate.

Typical trade names: Avisco Vinyon HH^R, Leavil, Rhovyl.

Vegetable Fibers - fibers of plant origin. Vegetable fibers are categorized as "hard" or "soft" according to the relative degree of fiber fineness and stiffness in the raw state. Hard fibers are obtained mainly from the leaves or stems of tropical plants. Soft fibers are generally obtained from the seed hairs or stems of a variety of plants. Soft fibers that are obtained from the stems of reedlike plants are also called bast fibers. Soft fibers are fine and soft enough for the manufacture of textile yarns. Hard fibers are coarse and are used mainly in heavy cordage and sacking.

Wet Spinning - a process in which filaments emerging from the spinneret pass directly into a chemical bath where they are solidified or regenerated. Acrylic and rayon are produced by this type of process.

ABBREVIATIONS USED IN THE FIBERS INDUSTRY

1. Abbreviations/Monomers

AN - Acrylonitrile, vinyl cyanide $H_2C = CH - C = N$	MW 53
AMS - Alpha Methyl Styrene, $C_6H_5 - C\ (CH_3) = CH_2$	MW 118
BD - Butadiene, Divinyl, $H_2C = CH - CH = CH_2$	MW 54
MA - Methyl Acrylate, $H_2C\ \ CH - COOCH_3$	MW 86
MMA - Methyl Methacrylate, $H_2C = C(CH_3) - COOCH_3$	MW 100
STY - Styrene, vinyl benzene, $C_6H_5 - CH\ \ CH_2$	MW 104
VA - Vinyl Acetate, $CH_3 - COO - CH = CH_2$	MW 86
VC - Vinylidene Chloride, $CH_2 = C - Cl_2$	MW 97
2VP - 2 Vinyl Pyrridine $C_5H_4 - N - CH = CH_2$	MW 105
VC - Vinyl chloride, $CH_2 = CH - Cl$	MW 62.5

2. Abbreviations/Polymers

ABS - Acrylonitrile Butadiene Styrene resin
NBR - Nitrile Butadiene Rubber elastomer
PAN - Polyacrylonitrile
SAN - Styrene Acrylonitrile copolymer
SBR - Styrene Butadiene Rubber elastomer
PBR - Polybutadiene Rubber elastomer

3. Abbreviations/Solvents

AC - Acetone, CH_3COCH_3
STC - Sodium Thiocyanate, NaSCN
ZCl - Zinc chloride, $ZnCl_2$
DMAC - DiMethyl Acetamide, $CH_3CON(CH_3)_2$
DMF - DiMethyl Formamide, $HCON(CH_3)_2$